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EDWARD HYATT, State Engineer

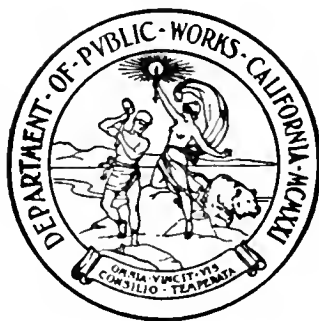
BULLETIN No. 40

SOUTH COASTAL BASIN INVESTIGATION

QUALITY OF IRRIGATION WATERS

A Report of Cooperative Work by the Bureau of Plant Industry,
U. S. Department of Agriculture and the Division of
Water Resources, State Department of
Public Works

1933



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LETTER OF TRANSMITTAL

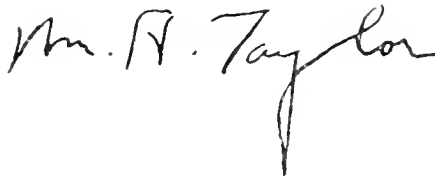
MR. EDWARD HYATT,
State Engineer,
Sacramento, California.

Dear Sir:

I transmit herewith for publication as a Bulletin of the Division of Water Resources a report "Quality of Irrigation Waters in the South Coastal Basin, 1933."

This report has been prepared by Mr. Carl S. Scofield, Principal Agriculturist in Charge, Division of Western Irrigation Agriculture of this Bureau, as the result of an investigation conducted cooperatively by the Division of Water Resources and the Bureau of Plant Industry.

Respectfully,

A handwritten signature in dark ink, reading "M. A. Taylor". The signature is fluid and cursive, with a long, sweeping tail on the final letter.

Chief, Bureau of Plant Industry,
U. S. Department of Agriculture.

Washington, D. C., July 24, 1933.

ACKNOWLEDGMENT

In the preparation and assembling of basic data for this report on the Quality of Irrigation waters in the South Coastal Basin, valuable assistance and cooperation have been rendered by many individuals, public service and commercial laboratories, city officials, water company officials and water users themselves. It is the courtesies extended to, and cooperation received by the Division of Water Resources which made possible the assembling of the mass of data upon which this report is based.

Acknowledgment is made for the water analysis data assembled as analyzed by: United States Department of Agriculture, Rubidoux Laboratory, Riverside; University of California, Graduate School of Tropical Agriculture and Citrus Experiment Station, Riverside; Water Resources Branch of the United States Geological Survey; Los Angeles County Flood Control District; Orange County Flood Control District; Los Angeles County Health Department Laboratory; City of Long Beach Engineering Laboratory; City of Los Angeles Department of Water and Power Laboratory; California State Department of Public Health, Bureau of Sanitary Engineering; Edward S. Babcock and Sons, Riverside; Smith-Emery Company, Los Angeles; Los Angeles Testing Laboratory, Los Angeles; Arthur R. Maas Laboratories, Los Angeles; Association Laboratory, Anaheim; The Twining Laboratory, Fresno; California Testing Laboratories, Inc., Los Angeles; Carl I. Wilkinson, formerly Wilkinson and Burke, Los Angeles; Santa Paula Citrus Fruit Association Chemical Laboratory, Santa Paula; Charles D. Samuels, Ph.D., Covina; J. H. Parsons Chemical Company; Dearborn Laboratories; Hollis and Rogers, San Francisco; Charles Dickens, Oakland; S. R. Mitchell, Consulting Chemist, Los Angeles; Griffon-Hassen Laboratory, Los Angeles; Chaffey Junior College, Ontario; Holly Sugar Corporation, Santa Ana; Corona Foothill Lemon Company, Corona; California Water Service Company, Redondo Beach; Standard Oil Company of California; Shell Oil Company of California; Union Oil Company of California; General Petroleum Corporation of California; and Waste Water Disposal Company, Fullerton.

Appreciation is due for water analysis data furnished by Continental Oil Company, Los Angeles; American States Water Service Company; The Irvine Company, Tustin; Gage Canal Company, Riverside; W. W. Hoy, Santa Ana; H. M. Bergen, Brea; R. F. Goudey, Sanitary Engineer, Los Angeles; W. T. Knowlton, Sanitary Engineer, Los Angeles; W. H. Wood and F. B. Laverty, Los Angeles; The Whiting Company, Los Angeles; City of Whittier; Los Angeles Department of Water and Power; and consent of both parties to Case No. 22046 (*Corona Foothill Lemon Co., a Corp., vs. C. E. Lillibridge et al.*), in the Superior Court of the State of California, in and for the County of Riverside.

Acknowledgment is made of assistance rendered by the Los Angeles County Flood Control District; Orange County Flood Control District; Water Resources branch of the United States Geological Survey; and others in collecting water samples for analysis.

The general information relative to the proper identification of the source of water analyzed was obtained by the Division of Water Resources with the valuable assistance and cooperation of those named above. Records in the files as furnished by those contributing data for Division of Water Resources Bulletin No. 39 aided materially in this respect. It is believed that this bulletin will prove useful to all interested in the quality of irrigation waters in the South Coastal Basin.

ORGANIZATION

STATE DEPARTMENT OF PUBLIC WORKS DIVISION OF WATER RESOURCES

EARL LEE KELLY-----*Director of Public Works*
EDWARD HYATT-----*State Engineer*

The South Coastal Basin Investigation,
of which this bulletin is a report on one feature,
was conducted under the supervision of

HAROLD CONKLING
Deputy State Engineer

and under the immediate charge of

GEORGE B. GLEASON
Senior Hydraulic Engineer

Collection of samples, assembly of analyses by other laboratories,
compilation of analytical data and location of data used in
making the map for this report was done by

EVERETT L. CLARK
Assistant Hydraulic Engineer

Original analyses for this report were made in
Rubidoux Laboratory of the U. S. Bureau of Plant Industry

by

JOSEPH M. SANCHIS
Junior Sanitary Engineer

ORGANIZATION

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PLANT INDUSTRY

Cooperating in
South Coastal Basin Investigation

WILLIAM A. TAYLOR-----*Chief of Bureau*

This report was written and conduct of the work of gathering
the data on which it is based was supervised by

CARL S. SCOFIELD
Principal Agriculturist in Charge
Division of Western Irrigation Agriculture

FOREWORD

This report is one of a series of bulletins issued in furtherance of a plan for conservation, development and utilization of the water resources of southern California.

Bulletin No. 32 of this division is devoted to the area known as the South Coastal Basin, and is a cooperative symposium of activities and plans of public agencies in Los Angeles, Orange, San Bernardino, and Riverside counties leading to conservation of local water supplies and management of underground reservoirs. In that bulletin it was stated that "A general investigation of the quality of underground water was made in 1904 by the United States Geological Survey. This should be resurveyed and investigation of the quality of imported waters should go forward. Work along this line is being done by Los Angeles County Flood Control District and by governmental agencies, but should be amplified."

Pursuant to this recommendation a plan of cooperation was agreed upon between the Director of Public Works and the Chief of the Bureau of Plant Industry, United States Department of Agriculture. That agreement: "An Investigation of the Quality of Irrigation supplies in the South Coastal Basin of California," became effective March 1, 1931. The present report is based upon the results of that cooperative investigation.

QUALITY OF IRRIGATION WATERS

By CARL S. SCOFIELD *

CHAPTER I

INTRODUCTION AND SUMMARY

The area here referred to as the South Coastal Basin includes the drainage basins of the Los Angeles, San Gabriel, and Santa Ana rivers, and of the creeks that discharge directly into the Pacific Ocean in the vicinity of Santa Monica, as well as of those so discharging in the vicinity of Newport Bay. The Basin has a maximum extent from east to west of 116 miles and from north to south of 56 miles. It contains approximately 3840 square miles or 2.46 million acres, of which 2200 square miles or 1.4 million acres are classed as valley or arable land.

According to the fifteenth census of the United States (1930) the three principal drainage areas of the Basin contain 419,159 acres of irrigated land with an investment of \$125,000,000 in irrigation enterprises. According to the same authority this irrigated land was served in 1930, in addition to the reservoirs, diversion works, and conduits for the utilization of surface waters, by 3685 wells, of which 46 were classed as flowing, having an aggregate discharge capacity of 5173 cubic feet per second.

In the investigation here reported the waters found in and adjacent to the Basin have been sampled at 1711 locations, of which 1433 represent wells, 107 represent surface streams, and 171 represent other sources. The total number of samples analyzed from all locations and assembled as the basis of this report is 4447, of which 3244 were from wells, 687 from surface streams, and 516 from other sources. Not all of the wells sampled are currently used for irrigation purposes; some of them are used chiefly for domestic or industrial purposes and others are not used.

Considered as a whole the irrigation supply of the South Coastal Basin is of low salinity and well suited to irrigation use. This is especially true of the surface waters draining from the high mountains that constitute the north boundary of the Basin. In certain limited areas the underground waters are of intermediate to high salinity or contain boron in concentrations that are regarded as potentially harmful to the more sensitive crop plants. The aggregate quantity of underground water potentially harmful because of high salinity or high boron content is relatively small.

From the standpoint of its geographical or geological features the South Coastal Basin may be divided into four subdivisions: (1) The

* Agriculturist in charge Division of Western Irrigation Agriculture, U. S. Bureau of Plant Industry.

high mountain watershed on the north, including the San Gabriel and the San Bernardino Mountains. These are essentially massive blocks of old granite. The soil weathering from the granite is low in potential soluble salts and the waters from this watershed are of very low salinity. (2) A series of upper basins skirting the south and southwest foothills of the high mountains, including the San Fernando Valley, the Upper San Gabriel Valley, and the Upper Santa Ana Basin. (3) These upper basins are partially bounded on the south and west by a series of low mountains or hills, including the Santa Susana and Santa Monica Mountains, the Merced Hills, the Montebello Hills, the Puente Hills, the Santa Ana Mountains, and the low divide between the South Coastal Basin and the San Jacinto Basin that extends from the Santa Ana Mountains to the San Jacinto Range. These low mountains are for the most part covered, or at least flanked, by soft rocks or indurated sediments which on weathering into soil yield some salinity, largely sulphates. (4) Between these low mountains and the coast lies the Coastal Plain, its gentle topography broken only by the low San Pedro Hills and a few scarcely perceptible crests of deeply buried anticlinal structures with some of which petroleum deposits are associated. The soils of both the upper basins and the Coastal Plain are composed largely of water-borne sediments from the adjacent hills and mountains.

It has been remarked that the surface waters flowing into the upper basins from the high granitic mountains to the north are of low salinity. This is generally true also for the underground waters found in the sediments adjacent to these high mountains. The surface waters draining from the low mountains of the inter-basin barrier are more saline, particularly in respect to sulphates and the underground waters found in the sediments adjacent to these hills possess similar characteristics. The surface drainage from the upper basins breaks through the inter-basin barrier at 3 points: (1) From the San Fernando Valley by way of the Los Angeles River between the Santa Monica Mountains and the San Rafael Hills; (2) from the Upper San Gabriel Valley through Whittier Narrows, between the southeastward extension of the San Rafael Hills and Puente Hills; and (3) by way of the Santa Ana River between Puente Hills and the Santa Ana Mountains. There is some movement of underground water through these same breaks in the barrier hills but its volume is not known and it is the writer's belief, based on the geological evidence, that the volume is not large.

In respect to certain of their constituent characteristics, the underground waters of the South Coastal Basin may be discussed in a regional sense. For example, in respect to total salinity, as measured by specific electrical conductance, the more saline waters occur: (1) along the foot of the low barrier that marks the Basin boundary southeast of the Riverside and Temescal Areas; (2) along the foot of the Puente Hills in the Lower San Gabriel and Lower Santa Ana Areas; (3) along the foot of the Santa Ana Mountains in the Santa Ana-Irvine Area; (4) on both sides of the Santa Monica Mountains in the San Fernando, Venice, and Los Angeles Areas; (5) in the vicinity of some of the oil fields in the Coastal Plain, e.g., Baldwin Hills, Signal Hill, and Huntington Beach, along the Inglewood Fault, and Monte-

bello Hills, Santa Fe Springs, and Coyote Hills, adjacent to the Whittier Fault; and (6) in isolated areas along the ocean front.

The higher concentrations of boron occur: (1) along the Santa Ana Fault, a branch of the San Andreas system, near the base of the San Bernardino Mountains; (2) along the San Jacinto Fault (Bunker Hill Dike) crossing the Upper Santa Ana Basin; (3) above the Whittier Fault in the Puente Hills; (4) adjacent to some of the oil fields in the Coastal Plain; (5) in a few isolated wells, as in the San Fernando Valley and in the Santa Ana-Irvine Area; and (6) in certain sewage effluents to which it is probably contributed from the waste waters of citrus fruit packing houses or from industrial plants.

The higher percentages of sodium occur in some of the deeper wells of the Coastal Plain, in some of those in the San Bernardino Basin, and in some industrial waste waters or in ground waters contaminated by such wastes.

The higher chloride concentrations occur: (1) in the Riverside and Temescal Areas where this element is the chief constituent of the higher salinity found there; (2) in the Coastal Plain adjacent to some of the oil fields; and (3) in isolated areas along the ocean front.

The higher sulphate concentrations occur in several of the areas adjacent to hills of the inter-basin barrier and elsewhere in waters held in similar sediments derived from shale. There is to be noted the occurrence of waters of very low sulphate content in the deeper sediments of the Venice, Redondo-Long Beach, and lower San Gabriel Areas. The low sulphate content of these waters is regarded as the result of sulphate reduction with the consequent increase in the concentration of bicarbonate and also in the amber color and hydrogen-sulphide odor of the water.

The occurrence of relatively high concentrations of nitrate, in the order of 100 parts per million or more, found in various parts of the Basin, is also to be noted. These concentrations are so high that, taken in connection with the various situations in which they occur, it is believed that they are not to be ascribed to recent industrial or agricultural sources, such as sewage contamination or the leachings from fertilized fields, but rather to antecedent natural conditions not yet understood.

During the year ending September 30, 1932, included in the period covered by this investigation, precipitation conditions in the Basin were approximately 30 per cent above normal as judged by the records for the period covered by precipitation data. In comparison with the seasons immediately preceding and following, however, the season of 1932 was one of very high precipitation. The discharges of the more important streams draining the high watershed of the Basin have been measured by the United States Geological Survey. The aggregate of the measured runoff into the upper basins for 1932 was 505,000 acre-feet, including 135,000 acre-feet of water imported through the Los Angeles Aqueduct and allocated to the San Fernando Valley. It is estimated that this aggregate volume of water contained slightly more than 120,000 tons of dissolved salts. The aggregate volume of surface water passing through the gaps of the inter-basin barrier to the Coastal Plain was 336,000 acre-feet, including 112,500 acre-feet of aqueduct

water allocated to that area and the measured run-off from the Santa Ana Mountains. It is estimated that this volume of water carried slightly less than 140,000 tons of dissolved salts. It is also estimated that during the year named the volume of discharge, chiefly as sewage effluent, from the Coastal Plain to the ocean was 166,000 acre-feet. The available data do not warrant an estimate of the quantity of dissolved salts carried in this last named discharge.

In respect to the sewage effluents and industrial waste waters discharged within the Basin it is estimated that the annual volume of sewage effluent so discharged is 27,000 acre-feet. The available data as to the volume of waters classed as industrial wastes are insufficient to warrant an estimate of their volume. The data as to the quality of the sewage effluent are inadequate for an estimate of the quantity of dissolved salts they may contribute to the water supply of the Basin. It is to be noted however, that occasionally at least, these effluents, possibly due to cannery wastes, contain such concentrations of boron as to be potentially harmful if the distribution of the waters were limited to local areas.

In the course of this investigation it has been found that there are important differences in the composition and concentration of the dissolved salts found in the underground waters of the various strata of the sediments in several areas. Attention is called to these conditions in the detailed discussion of the Areas. In general, and particularly in the Coastal Plain, it is found that the subsoil waters, i.e., the water in or just below the root zone, are more concentrated than the deeper waters usually drawn upon by irrigation wells. It has been found that the waters in deeper strata in the sections close to the ocean in the Coastal Plain are even less saline than the average of the surface waters now contributed to the Coastal Plain from the upper basins. From this it is inferred that the major portion of the waters now found in these deeper strata reached the Coastal Plain as floods from the high mountain watershed which are known to be of very low salinity and from rainfall on areas where penetration is possible. It has been found also that the intensity of boron contamination is much greater in some of the strata of the sediments of the San Bernardino Basin than in others. Also in the Redondo-Long Beach and Los Angeles areas it has been found that in the same wells marked difference may occur in the successive strata in respect to total salinity and to sulphate concentration.

Along the ocean front of the Coastal Plain where the static levels of the underground water are below sea level there has been some apprehension of sea-water intrusion. An inquiry involving the study of the quality of the water of 129 wells located in a zone 3 miles wide along the coast, delineated on Plates I and II, opposite pages 86 and 88, shows that there is some evidence of intrusion in the Venice Area and along San Pedro Bay. It appears that this intrusion has not yet progressed much beyond a mile from the beach in either of these sections and that elsewhere the evidence of intrusion is slight. It seems probable that some of the salinity contamination found to have occurred farther back from the beach may have been due to oil-well waters rather than ocean water. Along that portion of the ocean front in Orange County between Alamitos Bay and Newport Bay, not shown on the

plates, evidence of sea water contamination occurs in only two wells numbered C-1274-Q-14 and C-1274b-Q-14, both of which are located very close to the beach. While only partial analyses are available of samples from the standing water in these two wells, the high chloride concentration and their proximity to the beach indicate marine contamination. In the present inquiry use has been made of 5 criteria for testing the character of the high salinity found in certain wells and the use of these is believed to afford a better basis for determining the source of contamination than is afforded by the use of only one, the chloride concentration.

Although water from the Colorado River is not now used in the South Coastal Basin, construction has begun on an aqueduct to import it. This has appeared to warrant including in this report a statement concerning the quality of Colorado River water based on the analyses of a series of samples taken at the Grand Canyon gaging station and reported by the United States Geological Survey. The composition of the salts of the water as here reported is based on the means for a 5-year period, weighted as to the discharge of the river as represented by the component data. The quality of the water as so computed is compared with that of waters found in the Basin and the implications of its importation in reference to salt conditions in the Basin are discussed.

Aside from the general inquiry into quality of water now used or proposed to be used in the area, it was desired to estimate the amount of water which must be wasted into the ocean to take care of the accumulation of salts which occurs if adequate natural drainage does not exist, as is the case in the Coastal Plain. It is concluded that the sewage discharge of the area west of Los Angeles River will take care of this condition with a large margin to spare. In the area east of that river, the present sewage and drainage ditch wastes are believed to be not sufficient for this. A total of 35,000 acre-feet should be thus discharged annually to maintain the salt balance. It is concluded that about twenty per cent of the water entering this general area, of the quality of that of the Colorado River, should be wasted to maintain the balance. At present there appears to be no accumulation occurring in the pumping strata but in the subsoil water it is taking place.

For the purpose of this and of related investigations by the Division of Water Resources the South Coastal Basin has been divided into 5 districts for convenience in numbering the wells. These districts have been designated by the letters A, B, C, D, and E. These letters are prefixed to the well numbers in the detailed tables. District A includes, in general, the San Fernando Valley. District B includes the area south of the Santa Monica Mountains and west of Los Angeles River. District C includes the Upper San Gabriel Valley east to the Los Angeles-San Bernardino County line, the Coastal Plain east of Los Angeles River, and all of Orange County that lies within the Basin. District D includes the Chino Basin east of the Los Angeles County line, north of Santa Ana River, and west of the line of Meridian Avenue which runs north and south between the cities of Rialto and Colton. District E includes the rest of the Santa Ana River Valley lying within the Basin above the Riverside-Orange County line. These districts are the same and were adopted for the same reasons as are given in Bulletin No. 39 of the Division of Water Resources.

The numbers used for the designation of wells, for which water samples have been analyzed, are the same for identical wells as those used in Bulletin No. 39. Sources other than wells have been numbered according to a system described in the same Bulletin as "Location Numbers." A descriptive letter preceding the location number has been used to classify the source of the water sample. The letter S designates a source where water appears on the surface of the ground as a stream, spring, lake, open or tile drain, or imported water. The letter R denotes sewage water and W denotes industrial waste water. The letter following the number differentiates similar sources in the same quadrangle. The locations of all sampling points have been mapped and are shown on a map of the Basin (in pocket). Solid or open circles are used for wells and triangles for all other sources.

For this paper the Basin was further divided into 13 areas, largely delimited by natural boundaries, for convenience in tabulating and discussing the analytical data. The boundaries of these areas are given in the text and the quality of the water in each is discussed. In general the discussion takes up the upper valleys first, beginning with the San Fernando and proceeding eastward, then taking up those in the Coastal Plain beginning at the west.

CHAPTER II

COLLECTION OF SAMPLES AND ANALYTICAL DATA

The basic data for this report were obtained by the Division of Water Resources from analyses of water samples collected by the Division and numerous cooperating organizations and individuals. The samples were analyzed in a laboratory established at Riverside and maintained in cooperation with the United States Department of Agriculture. The methods used in collecting the samples will be discussed later.

Analytical data were also obtained from owners and several public service and commercial laboratories. The client's permission was obtained for release of data from commercial laboratory files. These data numbered 1489 complete and 1194 partial analyses, which were identified and mapped as to the original source of the sample.

Data were assembled and compiled in respect to samples of water from 1711 locations. These sources of water have been classified into nine different groups as follows: Wells, streams, springs, lakes, subsoil waters, imported waters, sewage effluent, industrial waste, and Pacific Ocean. The number of locations for each of these groups is shown in Table 1, which shows also the number analyzed by the Division of Water Resources and by cooperators.

TABLE 1

Classification as to the Number of Sources of the Water Samples analyzed by the Division of Water Resources, by Cooperators, and by Both

Source of water	Sampling points for which data were assembled, segregated as to number analyzed by			Total number of sampling points for each source
	D.W.R. only	D.W.R. and cooperators	Cooperators only	
Wells.....	496	281	656	1,433
Streams.....	59	20	28	107
Springs.....	8	4	14	26
Lakes.....	1	1	5	7
Subsoil waters.....	65	9	21	95
Imported waters.....	1	0	2	3
Sewage effluent.....	4	5	1	10
Industrial waste.....	6	1	17	24
Pacific Ocean.....	1	0	5	6
Totals.....	641	321	743	1,711

The total number of analyses assembled in tabular form is 4447, of which 1764 were analyzed by the Division of Water Resources. These data were tabulated on large size (19" x 24") typewriter paper and form the basis upon which this report was written. These tables, 26 in number, have not been included as a part of the report but are available in the files of the Division of Water Resources. The number of complete and partial analyses for each of the nine groups enumerated above are summarized in Table 2 which shows also the number of complete and partial analyses made by the Division of Water Resources and cooperators.

The terms “Complete Analysis” and “Partial Analysis” as used above, and as differentiated on the accompanying map, and as used elsewhere in the text are defined as follows: Complete Analysis—One in which at least three negative ions and enough positive ions were determined to permit the computation of per cent sodium. Partial Analysis—One in which at least the ehloride ion was determined but not enough of the others to permit the computation of the per cent sodium.

TABLE 2
Classification of Water Analyses as to Source, Type of Analyses, and Agency

Source of water	Number of complete and partial analyses assembled				Total number of analyses for each source
	Complete analyses by		Partial analyses by		
	D.W.R.	Cooperators	D.W.R.	Cooperators	
Wells.....	844	1,096	271	1,033	3,244
Streams.....	253	123	239	72	687
Springs.....	11	14	1	5	31
Lakes.....	3	10	2	0	15
Subsoil waters.....	48	7	37	46	138
Imported waters.....	1	162	0	18	181
Sewage effluent.....	21	42	23	1	87
Industrial waste.....	2	23	7	13	45
Pacific Ocean.....	1	12	0	6	19
Totals.....	1,184	1,489	580	1,194	4,447

Methods of reporting water analyses have varied in the past and vary at present with different laboratories. It was therefore necessary in many instances, where data were obtained from cooperators, to determine the method of analysis and of reporting used and to recompute the analyses into the equivalent constituents used by the Division of Water Resources in order to place them on a comparable basis. Data from these sources therefore do not appear as released but as they were recomputed. Specific electrical conductance and the determination of boron having but recently come into use, do not appear in the older analyses. In respect to sodium, a difference occurs in that many laboratories determine the alkaline bases as sodium by taking the difference between the sum of the negative ions and the calcium and magnesium, expressed as milligram equivalents per liter. Other differences have been found, but after the methods used by a particular laboratory were ascertained it became possible to make the conversions by the use of appropriate factors. The greatest difficulty arose in assigning correctly an analysis to the source from which the sample was obtained. When this could not be done with reasonable accuracy, the data were not used.

The importance of the manner of taking a sample, its adequate identification as to source, and the certainty that it represents that source are of the utmost importance. The need of accurate information in this regard can not be overemphasized, particularly where the data are to be used by others than the collector for future investigations. This need was early realized and has been fully confirmed by experience in assembling the data for this report.

A brief outline of the routine established by the Division of Water Resources and adhered to for all samples collected for its laboratory at Riverside is here presented.

The equipment for sampling consisted of one-half gallon clear glass bottles stoppered with first grade corks, a thermometer, gummed bottle labels, a collector's card for field notes, on the back of which the analyst reported his analysis, and an automobile with a wooden crate in the rear seat accommodating 34 bottles. The car was used both in the field and for transporting the samples to the laboratory.

The technique of obtaining the sample was to ascertain first whether the sample would be truly representative. The bottle was then rinsed with the water to be sampled, the rinsing water disposed of, the bottle refilled nearly to the top and securely stoppered. The gummed label was then filled out with the data necessary to identify the sample at the laboratory. This label always contained the assigned well number, the temperature, the date, collector's signature, and it remained on the bottle until the analysis was completed.

The identification of the source and circumstances pertinent to the interpretation of the analysis were recorded by the collector on a 4" x 6" card provided for the purpose. Space was provided for the owner's name and address, local designation of the source, use, location and description from nearest streets or other landmarks, date collected, location number, depth of well, size of casing, discharge, hours operated, whether isolated or not, equipment, whether records or log were available, remarks, and the collector's signature. This card was then sent to the laboratory and the analyst made his report in a form provided on the back of it. Thus the original field notes and analyst's report were filed together after transcription to the office record sheet, on which all data obtained from this sampling point were summarized.

Special care becomes necessary when sampling an operating well for the reasons that, (1) the well may be interconnected to one nearby, (2) it may be connected to a distribution system into which other wells may be discharging, (3) where distribution systems are under pressure for irrigation, valves may leak and allow the mixed water to flow back into the well, and (4) the well may not have been operated for some time, thus allowing the water in the casing to become stagnant or contaminated. The collector should ascertain these points and be sure that the pump is operating under conditions which permit taking a representative sample.

When the water standing in an open well casing is sampled, the depth from which the sample is taken becomes very important. A concrete example of this is cited for Well No. B-124-N-10, located northwest of Long Beach. Samples were obtained from the open casing just below the surface of the water on December 9, 1930, and June 23, 1931, with chloride contents of 72 and 80 parts per million respectively. A depth sampler was used on October 5, 1931, when samples were obtained just below the water surface and 63 feet below, with resultant chloride contents of 75 and 3,639 parts per million respectively. Well No. B-135-N-10, located in Wilmington, also sampled with a depth sampler from the open casing, again illustrates the importance of care. A bottom sample was found to contain 1,722 parts per million of chloride. Samples from the water surface in October, 1929, December, 1930, and June, 1931, showed a maximum chloride concentration of 110 parts per million.

In the sampling program of the Division of Water Resources, wells in general were selected from one to two miles apart over the valley floors. Where special study warranted, such as along the coast line where salt water intrusion might occur, or there was thought to be variation in quality through the vertical plane, they were spaced without regard to distance. The analyses obtained and assembled from cooperators filled in many gaps, consequently the general map of the area shows wells much closer together in many places.

Surface water samples were obtained periodically from streams where they left the mountains and again as they left the upper valleys to flow into the Coastal Plain. These samples were taken at 30-day intervals throughout the year to determine variations in quality due to seasonal change, climatic conditions, irrigation operations on the valley floors, and the salt burden carried by the water.

Subsoil waters were sampled mostly in the area between the Santa Ana and Los Angeles Rivers and back from the coastline for several miles. Test holes were drilled and samples obtained from tile and open drains to determine the quality of this water in comparison with that of the deeper waters. The waters were all from 2 to 20 feet below the ground surface.

The possibility of reclaiming sewage effluents was recognized and analyses of 44 samples from nine different plants were made. A total of 87 analyses from all sources were assembled for 10 plants. These data are insufficient for conclusions but serve to give some information for comparison with the quality of water now used for irrigation. No attempt was made to obtain a "sanitary analysis" of these waters. They were handled in the laboratory without the use of preservatives, the same as were waters from any other source.

A few samples were taken and data were assembled for springs, lakes, imported waters, industrial wastes, and the Pacific Ocean. The number of sampling points for these sources is given in Table 1 and the number of analyses reported is shown in Table 2.

A total of 1,853 analyses were made by the laboratory, of which some 800 were of samples collected by cooperators, using the methods outlined above. There were 44 samples analyzed for other State investigations which were collected outside the South Coastal Basin.

CHAPTER III

METHODS OF ANALYSIS AND INTERPRETATION

Methods of Analysis.

The so-called complete analyses, made in the laboratory of the Division of Water Resources by Mr. J. M. Sanchis, included the following determinations: (1) Specific electrical conductance; (2) Hydrogen ion concentration; (3) Carbonate and bicarbonate; (4) Chloride; (5) Sulphate; (6) Nitrate; (7) Calcium; (8) Magnesium; (9) Sodium. In addition to these the boron was determined in the Rubidoux Laboratory of the Division of Western Irrigation Agriculture by Messrs. L. V. Wilcox and John T. Hatcher. The so-called partial analyses included only (1) Specific electrical conductance; (2) Boron; (3) Carbonate and bicarbonate; (4) Chloride.

(1) Specific electrical conductance was determined by the conventional set-up with a Wheatstone bridge.¹ The results, expressed as reciprocal ohms at 25° centigrade ($K \times 10^5 @ 25^\circ C$), are taken to represent a measurement of the total dissolved electrolytes in the water and are used in lieu of the determination of total dissolved solids.

(2) Hydrogen ion concentration was determined by the use of color indicators and an apparatus in which colored glass discs were used as standards. These colorimetric methods were checked occasionally by the electrometric method.

(3) The carbonate and bicarbonate ions were determined by titration with 0.05 Normal sulphuric acid, using phenolphthalein indicator for the carbonate and methyl orange for bicarbonate.

(4) Chloride was determined by adding potassium chromate indicator to the solution resulting from the carbonate-bicarbonate titration and then titrating with 0.05 Normal silver-nitrate solution.

(5) Sulphate was determined gravimetrically as barium sulphate by the Official Method except that silica was not removed prior to the precipitation of the barium sulphate. The relatively small quantity of silica occurring in these waters does not appear to interfere so long as the volume of the aliquot is not concentrated below 75 to 100 cc.

(6) Nitrate was determined by the use of phenoldisulfonic acid according to the Official Method except that the color comparison was made with an apparatus in which colored glass discs were used as standards, these discs having been calibrated with solutions of known nitrate concentration.

(7) Calcium was determined by precipitation as the oxalate, filtered, redissolved in hot dilute sulphuric acid, and titrated with standard permanganate solution substantially according to the Official Method.

(8) Magnesium was determined by precipitation as magnesium ammonium phosphate, which was ignited and weighed as the pyrophosphate.

¹ Scofield, C. S. Measuring the Salinity of Irrigation Waters and of Soil Solutions with the Wheatstone Bridge. U. S. Dept. Agri. Circ. 232, July, 1932.

(9) Sodium was determined by precipitation as sodium-uranyl-zinc-acetate, and after washing and drying was weighed as such.

(10) Boron was determined by the electrometric method of titration.¹

Interpretation of Analyses.

Specific Electrical Conductance: This is a measurement of a definite physical property of a water sample, and is regarded by the writer as quite as significant a measure of the total dissolved solids as the results of a gravimetric determination in which salinity is expressed as parts per million. The conductance gives no clue as to the character of the salts in solution, it implies only the aggregate quantity of dissolved electrolytes. In respect to irrigation waters in the South Coastal Basin, if the boron concentration is below the limit of tolerance, and the sodium percentage is less than 60, it is believed that when the conductance is less than 100 the water is safe for general use. When the conductance is more than 100 but less than 300 it may be safe to use the water where drainage conditions are good or where the more tolerant crops are grown, but as the conductance approaches the upper limit of this range consideration should be given to the conditions of use and to the character of the salts involved. Waters having conductances above 300 are generally to be regarded as unsuited to irrigation use, although it should be understood that subsoil waters of that degree of salinity do not imply root zone conditions intolerable to many crop plants. In general terms it may be said that the soil solution or subsoil water is usually 5 to 8 times as concentrated as the irrigation water used.

Boron: The concentration of this constituent is expressed as parts per million of elemental boron in the solution. Experience in the South Coastal Basin has shown that under existing climatic conditions the critical concentration for this constituent in irrigation water lies between 0.5 and 1.0 p.p.m. where the water is to be used for the more sensitive crop plants such as lemons and walnuts.

Per Cent Sodium: This expression as used in respect to the quality of irrigation water takes into account the ratio of the sodium content to the sum of the calcium, magnesium, and sodium, the concentrations of all 3 constituents being expressed in terms of milligram equivalents per liter. In other words the per cent sodium is obtained by dividing the sum of the milligram equivalents of calcium, magnesium, and sodium into the figure for sodium and pointing off 2 places to the left.

$\left(\frac{\text{Na} \times 100}{\text{Ca} + \text{Mg} + \text{Na}} \right)$. The significance of this characteristic of the salt complex in irrigation water lies in the results of reactions of base exchange on the physical properties of the soil. If the dissolved salts are preponderantly those of calcium and magnesium; i.e., if the per cent sodium is low, then the reactions of base exchange are in the direction of maintaining good tilth and good permeability in the soil. On the other hand if the percentage of sodium is high the consequent reactions of base exchange in the soil tend in the direction of the replacement of calcium and magnesium by sodium in the exchange

¹ Wilcox, L. V. Electrometric Titration of Boric Acid. Ind. and Eng. Chem. Analytical Edition, Vol. 4, p. 38, 1932.

complex with the result that the soil becomes deflocculated and impermeable to water. Experience indicates that if the sodium percentage is below 50 there is little danger of impairing seriously the physical condition of the soil. If it is above 60, such danger exists. The critical ratio is believed to lie between 50 and 60.

Carbonate and Bicarbonate: These two constituents are closely related and their relative concentrations may change with changes in the content of carbon dioxide in the water. In the detailed tables on which this report is based the concentrations of both constituents, where both occur, have been reported in terms of bicarbonate. In the discussion of water conditions in the several areas the concentrations of bicarbonate are not mentioned because it is thought that this constituent has less agricultural significance than those that are mentioned. Occasionally waters are found in which the carbonates and bicarbonates comprise almost the whole of the anion complex. If in such waters the percentage of sodium is low the water is probably safe for irrigation use, but if the percentage of sodium is high the water may be alkaline in reaction and will be potentially harmful to the physical condition of the soil. The quantity of bicarbonate in well waters is the least variable of any constituent determined in these analyses.

Chloride: This constituent is the one most easily and most frequently determined in water analysis. It is important because it is one to which many crops are sensitive. As a result of long experience, it has come to be accepted in the South Coastal Basin that in respect to chlorides, irrigation water is safe to use if it contains less than 142 ppm (4 milligram equivalents). As the chloride concentration approaches 355 ppm (10 milligram equivalents) water becomes increasingly unsafe for irrigation use and above that limit its use is hazardous and should be safeguarded by good drainage and copious applications to keep the root zone leached.

Sulphate: Information as to the limits of tolerance of this constituent of irrigation water is much less precise than that in respect to chloride. It is recognized that if sulphate is associated with an abundance of calcium it is not likely to become injurious to crops because the limit of solubility of calcium sulphate (2000 ppm) is below the limit of crop tolerance. On the other hand the sulphates of magnesium and sodium are highly soluble and in the absence of sufficient calcium to precipitate sulphate from the soil solution, this constituent might reach concentrations injurious to crop plants. For convenience in classifying waters, concentration limits have been adopted for sulphate analogous to those used for chloride (in terms of milligram equivalents), i.e., those containing less than 4 milligram equivalents, 192 ppm, are classed as safe for irrigation use so far as this constituent is concerned, while those ranging up to 10 milligram equivalents, 480 ppm, are placed in the doubtful class, with those ranging above 480 ppm as possibly harmful. It must be emphasized that these limits are somewhat arbitrary and that the quality of water in respect to its sulphate content should be considered in conjunction with its calcium content or at least in conjunction with its percentage of sodium. If sulphate concentration and per cent sodium are high the water may be unsatisfactory for irrigation use.

Nitrate: This constituent rarely occurs in irrigation waters in harmful concentrations. It is reported for two reasons. Its occurrence has a certain geographic or geological significance. Also, it is sometimes used as an indication of the contamination of water supplies as by sewage effluents. It is to be noted that nitrate occurs in relatively high concentrations in some of the underground waters of the South Coastal Basin. It is the writer's view that these high concentrations should not be generally interpreted as evidence of sewage contamination, or as the result of the accumulation of fertilizer residues from cultivated lands. Both these sources may have contributed to some extent to the present condition but it is highly probably that they are both subordinate to other and natural conditions not yet fully understood.

Calcium, Magnesium, and Sodium: In the detailed tables of analytical data on which this report is based these three constituents have been recorded separately. In the discussion of the irrigation waters in this report they have been taken together as the components of the ratio designated "per cent sodium." The separate determination and reporting of these three constituents affords the basis for a criterion that is useful in determining the sources of salinity as discussed later in the case of suspected sea-water intrusion along the ocean front of the Coastal Plain.

CHAPTER IV

THE SAN FERNANDO AREA

The San Fernando Area includes essentially the valley of that name which constitutes the upper part of the drainage basin of the Los Angeles River. The valley is bounded on the north by the Santa Susana Mountains, on the northeast and east by the San Gabriel Mountains and the San Rafael Hills, on the south by the Santa Monica Mountains and on the west by the Simi Hills. The valley floor slopes to the south and southeast from an elevation of 1000 feet along the north side to 500 feet at the southeast corner. The city of San Fernando, in the northeast corner of the valley, lies at 1100 feet elevation.

The volume of drainage water contributed to the valley from the surrounding low mountains is small. The chief contributions are from the higher San Gabriel Mountains on the northeast, through Pacoima and Tujunga creeks. This is supplemented by a larger quantity of water imported from Owens River Valley through the Los Angeles Aqueduct, a part of which is allocated to the San Fernando Valley for irrigation use.

Surface Waters.

Of the various streams that carry drainage from the surrounding watershed into the valley, four are important enough to be gaged by the Water Resources Branch of the U. S. Geological Survey. The contributions of these streams as reported by that agency for the year ending September 30, 1932, are shown in Table 3. The contribution from the Los Angeles Aqueduct is reported by the Department of Water and Power of the city of Los Angeles. The quality of the water of each stream has been reported from the analysis of samples taken monthly at the gaging stations or less frequently if the stream was not flowing. From the discharge data and the analysis of a sample regarded as the best available representative of the annual discharge, the annual burden of dissolved solids has been computed and is also shown in Table 3. The composition of the salts entering the valley is shown in Table 12.

TABLE 3
The Volume of Water and Tons of Dissolved Solids Contributed to the San Fernando Valley
by Measured Surface Streams and the Los Angeles Aqueduct for the Year
Ending September 30, 1932

Stream	Volume in acre-feet	Tons dissolved solids
Pacoima Creek.....	8,390	2,160
Little Tujunga Creek.....	1,870	526
Haines Creek.....	29	8
Tujunga Creek.....	17,900	5,020
Los Angeles Aqueduct.....	134,800	44,100
Totals.....	163,000	52,000

NOTE.—An unestimated amount of water also discharges from unmeasured streams.

The water of the four local streams is all of low salinity and the salts in each are essentially of the same composition. The seasonal ranges in salinity are small because the waters are stored in reservoirs. The ranges in composition are: Conductance, 24.2 to 66.9; boron, .02 to .57 ppm; per cent sodium, 14 to 37; chloride, 4 to 13 ppm; sulphate, 15 to 116 ppm; nitrate, 0 to 2 ppm. The highest conductance, boron, per cent sodium, and chloride occur in the Big Tujunga, the highest sulphate in the Pacoima.

The Los Angeles River which drains the San Fernando Valley is formed by the junction of small intermittent streams from the watershed on the southwest side of the valley in the vicinity of Canoga Park. Following periods of rainfall it receives contributions from the washes that drain the watershed to the north and east. During the dry season the flow of the river is small, made up chiefly of irrigation waste waters and rising or subsoil water from adjacent irrigated land.

The stream has been sampled periodically at two points in the valley. At Location S3754, elevation 650 feet, where the samples represent chiefly subsoil waters. The composition ranges are: Conductance, 135 to 171; boron, .27 to .50 ppm; per cent sodium, 24 to 29; chloride, 41 to 59 ppm; sulphate, 389 to 558 ppm; nitrate, 8 to 20 ppm. At various times 12 samples of flood water have been taken at this same point. These are of lower salinity with the following composition ranges: Conductance (6 only), 15.9 to 104; boron (6 only), .14 to .25 ppm; per cent sodium, 24 to 34; chloride, 6 to 39 ppm; sulphate, 21 to 328 ppm; nitrate, 1 to 11 ppm.

The same stream has been sampled also each month at Location S3855, elevation 510 feet. The samples from this point represent not only the dry season flow of the stream but also the occasional flood waters and water from the Los Angeles Aqueduct discharged periodically from the Diaz Avenue power plant. The composition ranges for 16 samples taken at this point from August, 1931, to February, 1933, are: Conductance, 52.3 to 137; boron, .17 to .58 ppm; per cent sodium, 25 to 44; chloride, 9 to 59 ppm; sulphate, 86 to 470 ppm; nitrate, trace to 11 ppm.

In addition to these samples from the Los Angeles River, 8 samples have been taken from Verdugo Canyon Creek at Location S3973, elevation 760 feet. Their composition ranges are: Conductance, 36.8 to 60.6; boron, .01 to .10 ppm; per cent sodium, 19 to 22; chloride 9 to 20 ppm; sulphate (5 only), 46 to 108 ppm; nitrate, 1 to 2 ppm.

Samples have been taken at 4 points in the foothills north of the valley. One is from Bull Canyon Creek, Location S4801, elevation 1030 feet. This sample had a conductance of 120; boron, .52 ppm; per cent sodium, 31; chloride, 32 ppm; sulphate, 72 ppm; nitrate, none. The other 3 samples are from the same neighborhood. Location S4801A is from a spring, S4801B is from a tile drain, and S4811 is from a small reservoir. These locations are at 1000 to 1030 feet elevation and the composition ranges of the samples are: Conductance, 47.9 to 85.6; boron, .18 to .39 ppm; per cent sodium, 31 to 43; chloride, 32 to 66 ppm; sulphate, 8 to 72 ppm; nitrate, 0 to 1 ppm. The highest conductance, boron, and chloride are from the tile drain.

The volume of surface outflow from the San Fernando Valley for 1932, including that part of the water of the Los Angeles Aqueduct allocated to the Los Angeles District and that pumped from the valley for use in the city is shown in Table 4. This table also shows the quantities of dissolved solids carried by each component of the outflow as computed from the best available analysis for each. The discharge data are from the Department of Water and Power of the city of Los Angeles and the Los Angeles County Flood Control District. The composition of the salts carried by this combined outflow is given in Table 12.

TABLE 4

The Volume of Water and Tons of Dissolved Solids Passing on the Surface From the San Fernando Valley into the Los Angeles District During the Year Ending September 30, 1932

Source	Volume in acre-feet	Tons dissolved solids
Los Angeles Aqueduct	112,500	36,800
Los Angeles River Basin (pumped) ..	34,000	9,150
Los Angeles River at Dayton Ave. ..	15,200	3,700
Arroyo Seco	500	46
Totals	162,000	50,000

Imported Waters.

It has been noted above that water is contributed to the San Fernando Valley and to the Los Angeles District by importation from Owens River Valley, through the Los Angeles Aqueduct. It is reported by the Department of Water and Power, of the city of Los Angeles, that the discharge of the aqueduct for 1932 was 247,000 acre-feet, of which 135,000 acre-feet was allocated to the San Fernando Area and 112,000 acre-feet to the Los Angeles District. The quality of this aqueduct water has been under observation since July, 1928. A report of the conditions found during the 13 months ending in July, 1929, has been published.¹ For the period there reported the mean composition of the salts found was: Conductance, 40; boron, .68 ppm; per cent sodium, 57; chloride, 23 ppm; sulphate, 35 ppm; nitrate, not reported. During that period 56 samples were taken at the San Fernando Power House and the range in boron content for these was from .53 to .92 ppm.

During the year ending September 30, 1932, the aqueduct water has been sampled at the San Fernando Power House 13 times, at intervals of four weeks, and the samples have been analyzed for conductance, boron, and chloride at the Rubidoux Laboratory. The concentration ranges as reported for these three constituents are: Conductance, 29.6 to 57.5; boron, .46 to 1.44; chloride, 16 to 41 ppm. A sample taken from the lower San Fernando Reservoir July 21, 1932, had: Conductance, 50.8; boron, 1.15 ppm; chloride, 36 ppm. A sample from the Chatsworth Reservoir taken June 22, 1932, had the following composition: Conductance, 47.5; boron, .85 ppm; per cent sodium, 55; chloride, 28 ppm; sulphate, 42 ppm; nitrate, 2 ppm.

It will be observed that the boron content of the aqueduct water ranged higher during 1932 than the mean reported for 1928-29. It

¹ Scofield, C. S., and Wilcox, L. V., Boron in Irrigation Waters. Tech. Bull. No. 264, U. S. Dept. Agr., 1931.

is believed that this is a fact and that the conditions during the season of 1932 were different from those existing during the years 1928 to 1931. During the earlier period the aqueduct was sampled each week and the highest boron content reported from the outfall prior to March, 1932, was .92 ppm. The samples taken each four weeks from March to July, 1932, had the following boron contents in parts per million: .96, 1.24, 1.44, 1.25, and .96.

Underground Waters.

The water under the northeast side of the Valley is essentially different in quality from that under the southwest side, particularly in sulphate content, and the line of demarkation between the two is sharp. It is evident from these differences in quality that free circulation does not occur throughout the valley. In the vicinity of San Fernando, to its north and east, are two recognized subbasins here referred to as Pacoima subbasin and Tujunga subbasin.

Pacoima subbasin lies north of the center of the city of San Fernando and is bounded by an effective subsurface barrier of relatively impervious sediments running from the southeast edge of lower San Fernando Reservoir northeasterly, crossing Pacoima Wash about two miles south of the mouth of Pacoima Canyon. The Tujunga subbasin lies to the southeast of the Pacoima Basin and north of the buried extension of the fault scarp that forms the southwest side of the Verdugo Mountains and extending thence northwest through the center of San Fernando to the south limit of Pacoima subbasin.

The underground water plane of the Pacoima subbasin is above 1100 feet elevation and some 150 feet above that of the Tujunga subbasin which in turn is some 300 feet above the main San Fernando basin level. This latter slopes from 900 feet elevation near Chatsworth to 450 feet in the southeast corner of the valley, south of Burbank. The consistency of static water levels in the wells of the main basin indicate that there is an interconnected body of water under the floor of the valley with, however, certain differences in quality noted above and subsequently discussed.

In the Pacoima subbasin and north of the westerly extension of its south boundary 12 wells have been sampled. Eight of these may be classed as of low salinity, with the following ranges in composition: Conductance, 43.2 to 97.6; boron, .07 to .35 ppm; per cent sodium, 13 to 34; chloride, 6 to 82 ppm; sulphate, 17 to 123 ppm; nitrate, 0 to 23 ppm. Three of the wells classed as intermediate in salinity range in composition as follows: Conductance (two only), 82 to 110; boron, .26 to .57 ppm; per cent sodium, 13 to 26; chloride, 27 to 42 ppm; sulphate, 186 to 1000 ppm; nitrate 22 to 27 ppm. The remaining well of this group, No. 20a, is only 30 feet deep but the water is saline and high in boron: Conductance, 346; boron, 1.77 ppm; per cent sodium, 44; chloride, 1083 ppm; sulphate, none; nitrate, none. This well is on a hill and produces only a small amount of water. It is not believed to be representative of any considerable area.

In the Tujunga subbasin and watershed area of Tujunga Creek five wells have been sampled. The waters of all of them are low in salinity, ranging as follows: Conductance, 32.5 to 105; boron, .01 to .59 ppm; per cent sodium, 17 to 47; chloride, 7 to 16 ppm; sulphate, 3 to 350 ppm; nitrate, trace to 7 ppm. Of these wells No. 44a has the

highest conductance, chloride and sulphate, No. 41a the highest nitrate, and No. 47 the highest boron and per cent sodium. The sulphate content exceeds the chloride in wells 41a, 44a, and 47, the concentration of both being low.

In that part of the Area northeast of a line drawn from Chatsworth Street, at San Fernando Creek, to Los Angeles River, at Hollywood Way, including the upper valley of Verdugo Creek, 22 wells have been sampled. The waters of all of them are low in salinity, ranging as follows: Conductance, 30.9 to 110; boron, .01 to .33 ppm; per cent sodium, 17 to 40; chloride, 6 to 36 ppm; sulphate, 8 to 310 ppm; nitrate, trace to 27 ppm. Among these the highest ranges for conductance, sulphate, and nitrate are found in Well 93, boron in Well 96c, chloride in Well 95, and per cent sodium in Well 80c.

In the section west of the line described in the previous paragraph and extending to the western limit of the city of Los Angeles, 21 wells have been sampled. The composition ranges are: Conductance, 80.9 to 245; boron, .10 to 2.45 ppm; per cent sodium, 16 to 82; chloride, 28 to 142 ppm; sulphate, 110 to 1015 ppm; nitrate, 0 to 44 ppm. Three wells in this group deserve special comment because of high boron and per cent sodium. They are: No. 70b with boron 1.12 ppm; per cent sodium, 56; No. 77e with boron 2.45 ppm, per cent sodium 82; and No. 67a, said to draw its water from a stratum 65 feet below sea level, with boron .48 ppm, per cent sodium 80.

In the section southwest of the limits of the city of Los Angeles, in the valleys of Calabasas Creek and Dry Canyon Creek, five wells have been sampled. One, No. 57, has low salinity: Conductance, 77.4; boron, .45 ppm; per cent sodium, 56; chloride, 55 ppm; sulphate, 2 ppm; nitrate, none. The other four wells of this group have high salinity with composition ranges: Conductance, 217 to 452; boron, .34 to 1.98 ppm; per cent sodium, 32 to 91; chloride, 71 to 108 ppm; sulphate, 746 to 1392 ppm; nitrate, 4 to 50 ppm. Of these No. 57b, which is 353 feet deep, has the highest concentrations of all constituents.

In a previous paragraph is a reference to a sharp line of demarcation between the high sulphate waters under the southwest side of the valley and the low sulphate waters under the northeast side. The contrast in conditions on the two sides of the line is shown in the following table, No. 5. It is to be inferred that the underground water derived from the Santa Monica Mountains becomes charged with sulphate from that source, while the water derived from the northeast, including that imported from Owens Valley, through the Los Angeles Aqueduct, is not so charged.

TABLE 5

Comparison of the Conductance and Sulphate Content of Adjacent Wells on two Sides of a Line in the San Fernando Valley

Southwest side			Northeast side		
Well number	Conductance Kx10 ³ at 25°C	Sulphate content ppm	Well number	Conductance Kx10 ³ at 25°C	Sulphate content ppm
26a	158	601	31a	49	39
78f	150	598	80h	43.1	35
81k	132	408	84i	43.1	30
88g	110	310	88	57.3	61

CHAPTER V

THE UPPER SAN GABRIEL AREA

The Upper San Gabriel Area is bounded on the north by the high mountains of the San Gabriel Range; on the east it is partially cut off from the Upper Santa Ana Basin by the north ends of the San Jose Hills and the Puente Hills; on the south it is partially cut off from the Coastal Plain by Puente Hills, Montebello Hills and Merced Hills. The San Rafael Hills and their southeastward extension form part of the western boundary of the Area. The watershed drainage into the Area includes that of the San Gabriel Mountains from the Arroyo Seco, above the Devil's Gate Dam, eastward to and including San Dimas Creek. It includes also most of the small quantity of drainage from the San Jose Hills, from the north slope of Puente Hills, Montebello Hills, Merced Hills, and the eastern slope of San Rafael Hills. The valley floor of the central portion of the Area slopes from north to south having an elevation of 750 feet on the upper side and of 200 feet at Whittier Narrows where the surface drainage passes out between Puente Hills and Montebello Hills. The eastern and western portions slope generally toward the center and lie at higher elevations.

Surface Waters.

The volume of water contributed to the Area from the San Gabriel Mountains as reported by the Water Resources Branch of the United States Geological Survey for the year ending September 30, 1932, is shown in Table 6. The contributions reported in the table do not include all of the water of the Area because a number of small streams, including Rubio Creek, are not gaged and on some of the streams, as on Big Dalton Creek, there are diversions of water from above the gaging stations. Also no measurement is made of the drainage from the lower watersheds, on the east, south, and west. Mr. Gleason estimates that the volume reported in Table 6 represents about 90 per cent of the mountain watershed run-off. The discharge from these streams was much higher in 1932 than in the previous year when the total was 37,200 acre-feet. The mountain run-off in 1932 is estimated to be 83 per cent of the long time mean.

The quantities of total dissolved solids contributed by the mountain streams is shown in Table 6, and the composition of these for the Area as a whole is shown in Table 12. These waters are of very low salinity ranging in conductance from 27.4 to 84.9. The mean total salt content, weighted by discharges, is 166 ppm. The boron content is low, usually less than .3 ppm, in one case only reaching .41 ppm. The highest per cent sodium is 26. In general the chloride content is much less than that of sulphate, and the nitrate content is generally low, although one sample from Eaton Creek contained 10 ppm.

In respect to the surface waters leaving the Area through Whittier Narrows the volume for 1932 is shown in Table 7. The data of discharge in this table are from Mr. G. B. Gleason who includes in his estimate 25,000 acre-feet passing through the Narrows as subsurface flow. That item is not included in the table because of uncertainty as to its volume and composition. The tonnage of dissolved solids shown

in Table 7 is computed for each component of the discharge from the best available analyses. The composition of these salts is shown in Table 12.

TABLE 6

The Volume of Water and Tons of Dissolved Solids Contributed to the Upper San Gabriel Area by Streams from the San Gabriel Mountains for the Year Ending September 30, 1932

Stream	Volume in acre-feet	Tons dissolved solids
Arroyo Seco.....	5,290	1,480
Eaton Creek.....	1,230	246
Little Santa Anita Creek.....	442	120
Santa Anita Creek.....	4,010	1,100
Saw Pit Creek.....	1,560	511
Fish Creek.....	3,560	989
Rogers Creek.....	2,460	841
San Gabriel River.....	129,000	27,400
Little Dalton Creek.....	449	142
Dalton Creek.....	785	247
San Dimas Creek.....	2,970	1,240
Totals.....*	*152,000	34,000

* Estimated to be 90 per cent of total mountain runoff.

While the accuracy of these tonnage estimates may not be high, it is probably safe to assume that such differences between the incoming and outgoing salts as those shown in Table 12 in respect to the chloride constituents, 272 and 2581 tons, in some measure reflect the contribution originating within the Area from domestic and fertilizer sources and from hill run-off.

TABLE 7

The Volume of Water and Tons of Dissolved Solids Passing from the Upper San Gabriel Area Through Whittier Narrows as Surface Flow During the Year Ending September 30, 1932

	Volume in acre-feet	Tons dissolved solids
Flood water chiefly from valley floor.....	12,900	10,100
Flood water chiefly from mountains.....	32,500	7,080
Tri-City sewage.....	9,000	5,170
Rising water.....	17,800	4,600
Pumped water.....	12,000	3,200
Totals.....	84,000	30,000

Underground Waters.

In general the underground waters of this Area are of low salinity, only two wells having conductances above 100. However, the nitrate content is often relatively high; in several wells it equals or exceeds the chloride content in parts per million.

In the northwestern portion of the Area, in the vicinity of Pasadena, the underground water appears to be cut off from that of the rest of the Area by an underground barrier known as the Raymond Hill Dike. This Dike lies south of Wells 24a, 65a, and 66, extending thence to the junction of the two branches of Santa Anita Creek south of Well 104b. Above this Dike the underground water stands 500 feet or more above sea level while in adjacent wells south of the Dike it stands at 250 feet above sea level. The samples from wells above the

Dike show low salinity; the highest conductance is 37.7, the highest boron is .30 ppm, while the highest figures for the acid constituents are: Chloride, 38; sulphate, 50; nitrate, 30 ppm. With respect to per cent sodium, the waters of this part of the Area are low with the single exception of Well 101 in which it is 66. The water of this well is also the highest in conductance.

The waters below the Raymond Hill Dike and west of the Rio Hondo are all slightly more saline than those above the Dike. Only two wells (201a and 245a) show conductances lower than the highest of the wells in the upper area. The highest conductance for this portion of the Area is 71.1, found in Well 211a. The range in chloride content is from 7 to 77 ppm, that of sulphate from 10 to 113 ppm, and of nitrate from 1 to 27 ppm. The per cent sodium is generally low, the highest, 57, being associated with the highest conductance.

In that part of the Area between the Rio Hondo and the San Gabriel channel four wells have been sampled. These range in conductance from 34.8 to 50.7. The samples are all low in boron and in per cent sodium. The nitrate is approximately as high as the chloride, with the sulphate much higher than either.

East of the San Gabriel and north of Walnut Creek the range in conductance is from 34.7 to 88.3. There are only a few boron determinations for this part of the Area but the results are all low, less than .1 ppm. The per cent sodium is also low, 34 being the highest. Here also the nitrate content is approximately as high as the chloride, exceeding it in several instances.

The wells of the final group in the Area are located adjacent to the San Jose Hills, chiefly along Walnut and San Jose Creeks. In this group is found the highest salinity of the Area, the conductances ranging from 39 to 117.7. Here also the nitrate content is noticeably high and in the wells along San Jose Creek the sulphate content is much higher than the chloride. The percentage of sodium is generally low.

A comparison of the quality of the underground waters of the upper San Gabriel Area with that of the waters that rise to the surface at the Whittier Narrows tends to confirm the view that these waters at the Narrows represent the outflow of underground waters from the upper basin.

CHAPTER VI

THE UPPER SANTA ANA BASIN

Surface Waters.

The Santa Ana Basin above the lower canyon, where the river passes between the Santa Ana Mountains and the Puente Hills, receives drainage chiefly from the eastern end of the San Gabriel Mountains and the western end of the San Bernardino Range. The lower hills south of the Basin contribute very little surface flow. The San Jacinto River drainage area which lies southeast of the Santa Ana Basin, discharges into Lake Elsinore. This lake is held back by a low barrier near its northwestern end and in years of excessive precipitation it fills and overflows this barrier into Temescal Creek, a tributary of the Santa Ana River. The last record of such overflow was in 1916.

Of the numerous streams and washes that contribute surface water from the mountains to the Santa Ana Basin, 14 are of such size as to warrant gaging measurements. The volume of water contributed by them for the season ending September 30, 1932, as reported by the Water Resources Branch of the United States Geological Survey, is shown in Table 8. The total of these measured contributions is 190,000 acre-feet, while the corresponding total for the previous year as reported by the same authority was 71,600 acre-feet. The 1932 run-off is estimated to be 114 per cent of the long time mean. It will be understood that there are other streams, all small, that contribute water to the Basin but those here listed are estimated by Mr. Gleason to represent about 70 per cent of the total watershed run-off.

TABLE 8

The Volume of Water and Tons of Dissolved Solids Contributed to the Upper Santa Ana Basin From the San Gabriel and San Bernardino Mountains, for the Year Ending September 30, 1932

Stream	Volume in acre-feet	Tons dissolved solids
San Antonio Creek.....	20,700	4,060
Cueamonga Creek.....	6,390	1,320
Day Creek.....	2,440	465
Lytle Creek.....	28,800	5,720
Lone Pine Creek.....	1,120	755
Cajon Creek.....	10,700	5,860
Waterman Creek.....	2,180	591
Strawberry Creek.....	3,010	888
City Creek.....	8,210	972
Plunge Creek.....	6,500	654
Santa Ana River.....	65,000	7,260
Mill Creek.....	33,100	4,840
San Timoteo Creek.....	917	647
Totals.....	*190,000	34,000

* Estimated to be 70 per cent of total mountain runoff.

The tons of dissolved solids reported for each stream in Table 8 represent the sum of the tonnages of the constituents identified by analysis. The computations are based on the figures for annual discharge, and a single analysis selected as the best available representative of seasonal conditions. The composition of the salts carried by these streams is shown in Table 12.

Four of the creeks listed in Table 8 drain the eastern end of the San Gabriel Mountains. They are San Antonio, Cucamonga, Day, and Lytle creeks. Monthly samples were obtained from the first and last named, but only single samples, taken in March, 1932, from the other two. In respect to all these analyses, the conductances range from 25 to 38, the boron from a trace to .12 ppm, the per cent sodium, 7 to 15, the chloride from 0 to 4 ppm, the sulphate from 7 to 27 ppm, and the nitrate from 0 to 1 ppm. Thus the surface waters from these mountains are all of very low salinity.

Cajon Valley lies between the San Gabriel and the San Bernardino Mountains. It is drained by Cajon Creek, of which Lone Pine Creek is the principal tributary. Monthly samples have been obtained from both Lone Pine Creek and Cajon Creek at the gaging stations on the two streams just above their junction. The waters of both streams are more saline than those draining from the San Gabriel Mountains. In conductance, Lone Pine Creek ranges for the year from 74.4 to 87.4, while the corresponding range for Cajon Creek is from 56.5 to 78.5. The maximum boron content reported from either is .16 ppm. The per cent sodium in both ranges from 7 to 27, the chloride content from 7 to 22 ppm, the sulphate from 54 to 254 ppm, and the nitrate is 4 ppm or less except in one sample from Mathis Creek, a branch of Lone Pine Creek, for which 10 ppm is reported.

The drainage from the San Bernardino Mountains is represented by a number of streams, some of which, including Waterman Canyon Creek, City Creek, Santa Ana River, and Mill Creek have been sampled each month throughout the year. Others, including Devil Canyon Creek, Strawberry Creek, and Plunge Creek were sampled only once—in March, 1932. Five samples were taken from San Timoteo Creek.

Excepting Waterman Canyon Creek and San Timoteo Creek, these waters from the mountains are all of very low salinity. They range in conductance from 13.1 to 39, in boron from a trace to .16 ppm, and in per cent sodium from 7 to 34. The chlorides range from 0 to 10 ppm, the sulphates from 3 to 57 ppm, and the nitrate from 0 to 2 ppm.

Waterman Canyon Creek calls for special consideration. This stream crosses the fractured zone of the Santa Ana Fault, a branch of the San Andreas system, in the vicinity of the Arrowhead Hot Springs. The gaging station, Location S18820, elevation 2150 feet, is above the fault line and samples taken at that station show that the water is like that of the neighboring mountain streams with conductances ranging from 23.9 to 34.0 and with boron .02 ppm or less. Another series of samples taken from the same stream below the fault line, at Location S18822, elevation 1650 feet, shows the effect of the contribution from the Arrowhead Hot Springs. The conductances range from 34.8 to 131, and the boron content from .14 to 2.16 ppm. The chloride and sulphate contents are also much higher in the samples from the lower station, ranging up to 101 ppm for chloride and 399 for sulphate. A similar change in quality is shown in samples from Strawberry Creek taken from above and below the fault.

The water of San Timoteo Creek also differs from that of the other streams entering the basin. This creek drains the foothills toward San Geronimo Pass and also the low hills of shale and soft rock that divide the San Bernardino Basin from the drainage of San Jacinto River. The discharge of the creek is intermittent and of small volume.

The analyses of five samples are available. These range in conductance from 65.1 to 82.3, the boron from .02 to .12, and the per cent sodium from 34 to 37. The chloride content ranges from 30 to 38 ppm, the sulphate from 47 to 130 ppm, and the nitrate from 2 to 6 ppm.

The upper Santa Ana Basin is crossed by the San Jacinto Fault, known locally as the Bunker Hill Dike. The fractured zone along this fault line evidently serves as a barrier that impedes the movement downstream of underground water entering the basin through the porous gravels at the deltas of the streams from the mountains. The waters accumulating above the barrier, in what is known as the San Bernardino Basin, rise to the ground surface naturally, as at the head of Warm Creek, or through flowing or pumped wells, and thence pass over the barrier, chiefly in canals or pipe lines, for irrigation use. The quality of this rising water is uniform and of low salinity as is shown by the analyses of 101 samples taken from the irrigation canals mentioned. Its conductance ranges from 34.6 to 58.6, its boron content from a trace to .37 ppm, except for one sample for which the boron is reported as .98 ppm. This high figure may be the result of an analytical error or it may be due to an unusual contribution of sewage effluent to one of the canals. The per cent sodium ranges from 14 to 52, the chloride content from 9 to 44 ppm, the sulphate from 21 to 115 ppm, and the nitrate from 0 to 22 ppm.

The main channel of the Santa Ana River is usually dry for some distance below where it crosses the Bunker Hill Dike. It carries water in this section only at flood times. At a point about one mile below La Cadena Avenue bridge, water begins to appear in the channel as return flow from adjacent irrigated lands. From there to the head of the Lower Canyon, below Prado, there is usually water flowing in the channel and its discharge is measured by the United States Geological Survey at the following points. (1) Riverside Narrows, Location S16952; (2) near Hamner Avenue bridge, Location S16854; (3) Auburndale bridge, Location S16807; (4) near A. T. and S. F. Railway bridge, Location S15851; and (5) at the Riverside-Orange County Line, Location S15822. Substantially all of the water flowing in the river channel from Riverside Narrows to the County Line represents seepage or return flow from adjacent irrigated lands, except during the occasional flood periods.

The salinity of this seepage water is somewhat higher than that of the rising water of the San Bernardino Basin. Five samples taken at points above Riverside Narrows had conductances ranging from 55.6 to 62.7. Monthly and other samples, 106 in number, taken at various points along the stream from Riverside Narrows to the County Line show that there is no significant increase in salinity in the downstream direction in this section of the channel. The range in conductance is from 59.1 to 116 and in chloride content from 55 to 144. The high points both in conductance and in chloride content are from a sample taken on the south side of the stream near the delta of Temescal Creek and may represent local contamination. A series of monthly samples from the gaging station at the County Line, where the river flow is blended, show a maximum conductance of 86.1 and a maximum chloride content of 99 ppm.

In view of the known fact that along the section of the Santa Ana River from Riverside Narrows to the head of the lower Santa Ana Canyon the underground waters on the north side, from the Chino Area, are much less saline than those on the south side of the river, it was thought advisable to take a series of samples from the two sides of the stream for comparative analyses. These samples were collected by Sanchis and Troxel and the results are shown in Table 9. The samples were taken as close to the bank on each side of the stream as it was possible to immerse the bottle where there was free stream flow.

TABLE 9
The Conductance, Bicarbonate and Chloride Content of Water Samples from
Opposite Sides of the Santa Ana River

Location	Elevation	Date of sampling 1932	Discharge of stream cfs	Side of stream	Lab. No.	Kx10 ⁵ at 25°C	Bicarbonate (HCO ₃) ppm	Chloride (Cl) ppm
Riverside Narrows, S16952.....	690	Mar. 9	52	North	781	81.1	305	84
				South	779	81.1	305	84
Hamner Ave. Bridge, S16845.....	565	May 19	36	North	1006	76.1	238	90
				South	1004	77.0	241	94
One-half mile below Hamner Ave. Bridge, S16835.....	555	Mar. 9	65	North	783	77.5	296	80
				South	784	79.4	299	85
Auburndale Bridge, S16807.....	520	Mar. 9	84	North	787	65.0	268	59
				South	785	72.8	284	73
Auburndale Bridge, S16807.....	520	May 19	57	North	1009	60.3	238	55
				South	1007	68.2	235	75
Auburndale Bridge, S16807.....	520	Sept. 15	43	North	1378	59.1	220	57
				South	1380	64.6	220	71
A.T. & S.F. Railway Bridge, S15851.....	450	Mar. 9	129	North	790	84.9	311	62
				South	788	79.9	290	80
A.T. & S.F. Railway Bridge, S15851.....	450	May 19	82	North	1013	78.7	278	75
				South	1011	77.8	262	85
A.T. & S.F. Railway Bridge, S15851.....	450	Sept. 15	60	North	1385	78.0	229	87
				South	1387	80.0	247	91
County Line, S15822.....	410	Mar. 9	141	North	795	82.9	302	75
				South	793	82.3	299	75
County Line, S15822.....	410	May 19	77	North	1016	77.7	265	82
				South	1014	78.3	265	82
County Line, S15822.....	410	Sept. 15	60	North	1389	78.1	235	91
				South	1391	78.5	235	89

The analytical results in the table show that at Riverside Narrows there was no difference between the two samples. At Hamner Avenue bridge the water on the south side was very slightly more saline. At the next station, one-half mile below the Hamner Avenue bridge, the water on the south side was again slightly more saline. At the Auburndale bridge, where three sets of samples were taken, the water on the south side of the stream was consistently more saline and the differences are large enough to be significant. At The A. T. and S. F. Railway bridge conditions appear to be different. Here the samples from the north side of the stream for the first two sets (March 9 and May 19) were higher in conductance than those from the south side. The chloride contents, however, were higher in the samples from the south side.

Fortunately, in these samples the sulphate contents were also determined. In the samples of March 9 the sulphate content of the north-side sample was 119 ppm, while that of the south-side sample was 65 ppm. In the samples of May 19 the sulphate in the north-side sample was 72 ppm and in the south-side sample 61 ppm. These differences in sulphate content help to explain the conductance figures. The samples taken on September 15 from this location show the characteristically higher salinity for the south-side sample. In these two the sulphate contents were approximately the same. In the three pairs of samples taken at the County Line the salinity is substantially the same for the two sides of the stream, as it was at Riverside Narrows. The implication is that the seepage waters contributed to the stream from its two sides are of different salinity and that even in such a small stream, often less than 100 cfs, the blending of the waters is not immediate.

The condition of higher salinity in the water contributed from the south side of the stream is confirmed by two samples from the Lillibridge ditch at Location S16789, in September and October, 1931. These samples had conductances of 137.2 and 139, and chloride contents of 176 and 183 ppm. It is also confirmed by the analyses of two samples taken from the river at Location S16779B (Elevation 480 feet). One of these, taken from the south side of the stream on September 13, 1931, had a conductance of 116 and a chloride content of 144 ppm, while the other, taken at the same station on November 28 but as a composite of the whole stream, had a conductance of 70 and a chloride content of 66 ppm.

Temescal Creek joins the Santa Ana River from the south. It is ordinarily dry except after rains and only two analyses of its storm-water flow are available. The two samples were taken at the Sixth Street bridge, Corona, on February 15, 1932. One of these was from a small stream along the east side of the channel and had a conductance of 45.4 with a chloride content of 30 ppm. The other was from a stream on the west side of the channel, thought to represent chiefly storm water from Corona city streets, and had a conductance of 97.3 with a chloride content of 21 ppm; the sulphate content was not determined. The boron contents of these two samples were .02 and .06 ppm. Cold Water Creek is a tributary of Temescal Creek from the Santa Ana Mountains. It was sampled at Location S14904, Elevation 1300 feet, near Glen Ivy, on February 15, 1932, and found to have a conductance of 24.2, a boron content of .02 ppm and a chloride content of 30 ppm.

Chino Creek joins the Santa Ana River from the north. Its discharge represents in part, drainage from the east end of Puente Hills, and in part drainage and rising water from the Chino Area. One sample taken from a small tributary of Chino Creek, on the west, at Location S1952, Elevation 700 feet, beside the road to Carbon Canyon, on March 10, 1932, had a conductance of 217, a boron content of 0.24 ppm, and a chloride content of 220 ppm. This sample, like those taken from Carbon Canyon Creek and Soquel Canyon Creek (reported in the chapter on the lower Santa Ana Area), suggests that the drainage from Puente Hills is of high salinity. Reynolds slough, at Location S16777, Elevation 510 feet, represents rising water in the lower part

of the Chino Area and waste water from irrigation in that area. It is a tributary of Chino Creek from the east. Three samples from that slough, taken in September, October, and November, 1931, showed conductances ranging from 55 to 69, with chloride contents ranging from 14 to 28 ppm, or much lower salinity than the upper tributary from the west. A series of monthly samples from the main stream of Chino Creek at the gaging station, Location S15850, Elevation 460 feet, had conductances ranging from 64.2 to 98.6; boron contents from .06 to .18 ppm; per cent sodium from 24 to 36; chloride from 23 to 36; sulphate from 39 to 232 ppm; and nitrate from 1 to 6 ppm.

The main stream of the Santa Ana River as sampled at the gaging station at the County Line between Riverside and Orange counties, Location S15822, Elevation 410 feet, is assumed to represent the outflow as surface water of the drainage from the upper Santa Ana Basin. There are available 11 analyses of samples from this station taken at various times from March, 1919, to November, 1930. There are also 24 analyses of samples, including monthly samples taken during the period from September, 1931 to February, 1933. From these analytical data, together with the estimate as to the total volume of discharge at this station for the year ending September 30, 1932, made by the Water Resources Branch of the United States Geological Survey, it is possible to compute the salt burden carried by the stream at this point. The volume of discharge for the year was 83,300 acre-feet and the total burden of dissolved solids was 56,321 tons, or a mean salinity of 497 ppm. The composition of the salts carried by the river at this station is shown in Table 12.

Lakes, Springs, and Subsoil Waters.

Bear Lake is a mountain reservoir on a tributary of the Santa Ana River in which water is stored at 6700 feet elevation for irrigation use in the Santa Ana Basin. A sample of this water taken on March 28, 1931, had a conductance of 24.1; boron, .01 ppm; sodium per cent, 12; only a trace of chloride; and 10 ppm sulphate.

Lake Norco is an artificial body of water located north of Corona (S16827), not far from the Santa Ana River, at 640 feet elevation. A sample taken from it in November, 1931, had the following composition: Conductance, 83; boron, not determined; per cent sodium, 62; chloride, 135 ppm; sulphate, 51 ppm; nitrate, not determined.

Hole Reservoir, located north of Arlington (S16934) at 720 feet elevation, is used for the storage of irrigation water. A sample taken in January, 1920, contained: Per cent sodium, 52; chloride, 226 ppm; sulphate, 90 ppm; nitrate, 2 ppm.

Lost Lake is a small lake in the valley of Lone Pine Creek near Cozy Dell, at 2760 feet elevation. It is fed chiefly by springs forced to the surface by local faulting. Similar springs occur from the same cause on the Flying W ranch, $1\frac{1}{2}$ miles up Lone Pine Creek at 2950 feet elevation. The water from these two groups of springs is similar in character: Conductance, 94.1 and 99.2; boron, .11 and .08 ppm; per cent sodium, 10 and 15; chloride, 16 and 17; sulphate, 239 and 214 ppm, with only a trace of nitrate.

Miller Hot Spring, in the Lytle Creek trough at 2950 feet elevation, appears to show the influence of its proximity to the San Jacinto

Fault in its high temperature, high boron, and high sodium. Its Conductance: 53.1; boron, .80 ppm; per cent sodium, 87; chloride, 28 ppm; sulphate, 87 ppm; with no nitrate.

The Arrowhead Hot Springs, located on the Santa Ana Fault at 1900 feet elevation, are more striking examples of the effect of hot gases escaping from the earth through fault fractures. Samples have been taken from four of these springs. Their conductances range from 125 to 163.3; the boron contents from 2.06 to 2.94 ppm; per cent sodium, 79 to 88; chloride, 51 to 84 ppm; sulphate, 419 to 545 ppm; with nitrates not reported.

Farther east, along the Santa Ana Fault line, at Location S18842, elevation 1560, is another warm spring: Conductance, 36; boron, .44 ppm; per cent sodium, 60; chloride, 16 ppm; sulphate, 31 ppm; nitrate, 1 ppm. Still farther east and on the same fault line, near where it is crossed by the Santa Ana River, at Location S19027, Elevation 2200 feet, is another hot spring of which the water has: Conductance, 128; boron, .42 ppm; per cent sodium, 78; chloride, 11 ppm; sulphate, 542 ppm; nitrate, not reported.

On the hill slope east of Riverside are two springs, tributary to Sycamore Canyon, one at S17054, and the other at S17094, elevations 960 and 1460 feet respectively. Their compositions are: Conductance, 116 and 47.4; boron, .18 and .08 ppm; per cent sodium, 25 and 44; chloride, 211 and 75 ppm; sulphate, 78 and 12 ppm; nitrate, 39 and 18 ppm. Another spring on the north slope of Box Spring Mountain, S17903, at 1700 feet elevation is reported as containing 50 ppm chloride. A spring emerging from the south bank of the Santa Ana River near Riverside, S16983, at 720 feet elevation, has the following composition: Conductance, 86.6; boron, .17 ppm; per cent sodium, 39; chloride, 105 ppm; sulphate, 32 ppm; nitrate, 14 ppm.

On the low ridge that divides the San Jacinto Drainage Basin from the Riverside and Temescal Areas of the South Coastal Basin, there are eight small springs that have been sampled. Four of these, S16178 at 1900 feet elevation, S16157 at 1600 feet, S16136 at 1550 feet, and S16124 at 1410 feet are of low salinity, with the following composition ranges: Conductance, 22 to 49; boron, .09 to .15 ppm; per cent sodium, 22 to 49; chloride, 34 to 115 ppm; sulphate, 12 to 41 ppm; nitrate, 0 to 1 ppm. Two of the eight springs in this group are classed as of intermediate salinity, S16138 at 1900 feet elevation, and S16147 at 1600 feet. The former is represented by one sample for which only chloride is determined (225 ppm); the latter by three samples for only one of which have conductance and boron been reported. Following is the composition of S16147: Conductance, 114; boron, .18 ppm; per cent sodium, 29; chloride, 160 ppm; sulphate, 84 ppm; nitrate, trace. The remaining two springs are of high salinity. They are S16156 and S16156A, at 1545 feet elevation. Their compositions are: Conductance, 356 and 403; boron, .16 and .17; per cent sodium, 50 and 51; chloride, 819 and 914 ppm; sulphate, 390 and 426 ppm; nitrate, trace and 1 ppm. Further reference is made to these springs in the chapter on the sources of salinity in the Riverside and Temescal Areas.

In the vicinity of Arlington the subsoil water has been sampled at five locations, at four of which it was found to be of low to intermediate salinity. These samples, 13 in number, are all from tile drains northwest of Arlington. They range in composition as follows: Conductance, 64.5 to 175; boron, .02 to .37 ppm; per cent sodium, 24 to 48; chloride, 16 to 419 ppm; sulphate, 11 to 158 ppm; nitrate, trace to 23 ppm. Another drain in that same Area is represented by one sample which contained 740 ppm chloride.

CHAPTER VII

THE CHINO AREA

The Chino Area lies north of the Santa Ana River, east of the Upper San Gabriel Area and west of San Jacinto Fault. It receives the run-off from the San Gabriel Mountains from Thompson Creek east to Lytle Creek. The quality of that run-off is discussed in the chapter on the Surface Waters of the Upper Santa Ana Basin. The irrigated land of the Chino Area lies on a plain that slopes south from the foothills to the Santa Ana River, having an elevation of 1250 feet at the foothills, of 700 feet at Riverside Narrows, and 500 feet at the mouth of Chino Creek. This plain is constricted as it approaches the river by the Jurupa Hills on the southeast and the Puente Hills on the southwest, the latter draining into Chino Creek. The underground water is evidently not freely interconnected throughout the Area. There is an underground barrier which extends northeasterly from the east end of San Jose Hills, intersecting San Antonio Wash near Foothill Boulevard and terminating at the edge of the hills about one-half mile east of Euclid Avenue near the north city limits of Upland. The section above this barrier is known locally as Pomona Basin. Another Basin, known locally as the Cucamonga Basin, lies to the east. It is delimited by an underground barrier which extends southeasterly from near the north end of Euclid Avenue to intersect Foothill Boulevard near the east city limits of Upland, thence swinging east along Foothill Boulevard to Cucamonga Wash. From this point it swings northeast along a line passing south of Well No. 1012a and intersecting Highland Avenue near Haven Avenue. Beyond this point its location is indefinite. The underground water plane stands some 200 feet higher above these underground barriers than below them. South of the Pomona and Cucamonga Basins the plane of the underground water table slopes to the Santa Ana River, but less steeply than the ground surface so that springs and artesian wells are found in the lower part of the Area. The underground waters are generally of low salinity, with no appreciable difference in quality between those in the Pomona Basin, Cucamonga Basin, and the others of the northern part of the Area.

Within the Pomona Basin, as delimited above, 16 wells have been sampled. They are all of low salinity with the following composition ranges: Conductance, 26.4 to 50.5; boron, trace to .47 ppm; per cent sodium, 10 to 95; chloride, 2 to 25 ppm; sulphate, 15 to 61 ppm; nitrate, 1 to 13 ppm. The highest conductance and chloride occur in Well No. 586, and the highest boron and nitrate in No. 622a. The highest per cent sodium occurs in No. 670s which has the lowest conductance. The next highest per cent sodium of 61 and the highest sulphate occur in Well No. 583b. Wells Nos. 665 and 711 have per cent sodium of 54 and 55, respectively. Of these four wells with per cent sodium in excess of 50, three of them, Nos. 670s, 665, and 711, are located just above the underground barrier described as the south limit of the basin. They do not differ materially from other wells of the Basin except in respect to per cent sodium and range in depth from 450 to 690 feet. Well No. 583b is 275 feet deep and is one of the two wells less than 450 feet deep.

Within the Cucamonga Basin, as delimited above, 14 wells have been sampled. All of them are of low salinity with the following composition ranges: Conductance, 27.9 to 42.5; boron, trace to .08 ppm; per cent sodium, 9 to 48; chloride, 4 to 12 ppm; sulphate, 11 to 61 ppm; nitrate, 0 to 30 ppm. The highest conductance and sulphate occur in Well No. 1107, the highest boron in No. 1107o, the highest per cent sodium and chloride in No. 1117, and the highest nitrate in No. 1118.

In the section of the Area south of the Pomona and Cucamonga Basins and the mountains, to Edison Avenue, Adams Avenue and Mission Boulevard, 55 wells have been sampled. Their composition ranges follow: Conductance, 28.0 to 94.1; boron, .01 to .22 ppm; per cent sodium, 5 to 38; chloride, 0 to 252 ppm; sulphate, 2 to 94 ppm; nitrate, 0 to 22 ppm. The highest conductance occurs in Well No. 762, the highest boron in No. 744h, the highest per cent sodium in No. 1092h, the highest chloride and sulphate in No. 1092e, and the highest nitrate in No. 673.

In the section south of the one just described and extending to the Santa Ana River, 39 wells have been sampled. Of these, 14 are of very low salinity having conductance of 50 or less. The composition ranges of these 14 follow: Conductance, 19.8 to 50; boron, .01 to .08 ppm; per cent sodium, 20 to 55; chloride, 2 to 32 ppm; sulphate, 6 to 27 ppm; nitrate, 0 to 9 ppm. Another group of 20 wells includes those of slightly higher salinity but classed as undoubtedly safe for irrigation use, with the following ranges: Conductance, 56.2 to 100; boron, .02 to .28 ppm; per cent sodium, 15 to 44; chloride, 14 to 98 ppm; sulphate, 12 to 114 ppm; nitrate, 3 to 27 ppm. Finally, there are five wells having conductances of more than 100. These are notable chiefly as indicating sources of salinity contamination in the lower part of the Area. Three of them, Nos. 780a, 783a, and 789d, are located along Chino Creek and probably reflect contamination from Puente Hills. Another, No. 803b, is a shallow test well, eight feet deep, located close to Santa Ana River below the junction of Temescal Creek; while the last, No. 975d, is a shallow well, 30 feet deep, in low ground south of Jurupa Hills. The composition ranges of the five wells follow: Conductance, 104 to 184; boron, .11 to .48 ppm; per cent sodium, 32 to 51; chloride, 28 to 320 ppm; sulphate, 68 to 186 ppm; nitrate (two only), 11 to 13 ppm.

CHAPTER VIII

THE SAN BERNARDINO AREA

The San Bernardino Area includes that part of Upper Santa Ana Basin, except the San Timoteo Area, that lies east of the Bunker Hill Dike or San Jacinto Fault. It receives a large part of the drainage from the south slope of the San Bernardino Mountains and much of this drainage is absorbed by the gravel fans of the stream deltas and percolates through subsurface strata in a southwesterly direction until its further progress is impeded by the anticlinal folding or faulting that constitutes the western boundary of the Area. The sediments of the valley floor are several hundred feet deep and, filled with water as they are, constitute a storage reservoir of large capacity. Hydrostatic conditions in the Area are such that some of the wells in the western and lower part of it are flowing. The underground water of the Area serves not only to supplement surface waters from the mountains, diverted for irrigation, but a large volume, in the aggregate, is exported from the Area for irrigation and domestic use in the adjacent lower Areas.

Underground Waters.

In that section of the San Bernardino Area south of the Santa Ana River and east of the city limits of Redlands, including the delta of Mill Creek, eight wells have been sampled. Their waters range in conductance from 32.2 to 54.4. The highest boron content is .08 ppm and the highest per cent sodium is 21. The chlorides range from 2 to 16 ppm, the sulphate 21 to 63 ppm, but the nitrates are relatively high, ranging from 0 to 11 ppm.

In the next section to the west, extending to Tippecanoe Street, also south of the river, ten wells have been sampled. Of these the waters of the three that are located near the channel of San Timoteo Creek, Nos. 103, 103c, and 107L, are somewhat more saline. Their conductances range from 69.6 to 85.5 but the boron contents are low, .04 to .09 ppm, and the sodium percentages are not high, 39 to 48. The chlorides range below 50 ppm, the sulphates from 49 to 78 ppm, but in one, No. 107L, the nitrate content is 22 ppm. For the other seven wells in this section the conductances range from 38.4 to 45.6, the boron contents are all below .13 ppm, while the highest sodium percentage is 26. The chloride contents range below 28 ppm, the sulphates between 22 and 38 ppm, while the nitrates range up to 22 ppm.

On the north side of the river, east of Sterling Street, 20 wells have been sampled. Twelve of these may be taken as representing the characteristically good water of the upper part of the Area. Their composition ranges are as follows: Conductance, 23.2 to 40.9; boron, .04 to .13 ppm; per cent sodium, 24 to 50, except No. 50h which is 77; chloride 4 to 18 ppm; sulphate, 8 to 55 ppm; and nitrate, 2 to 13 ppm. The remaining eight wells fall into two groups. One of these includes five wells above Highland, four of them north of Highland Avenue. Four of these five appear to be slightly contaminated with boron and to contain a high percentage of sodium. The fifth is a shallow well

and its boron content was not determined. The range in composition of the four follows: Conductance, 34 to 59.9; boron, .16 to 1.03 ppm; per cent sodium, 51 to 86; chloride, 14 to 20 ppm; sulphate, 20 to 83 ppm; nitrate, 2 to 18 ppm. There is a fault line running in an east to west direction crossing the delta of City Creek, near Highland Avenue, from which these wells are probably contaminated. The other group of three wells, Nos. 46n, 50e, and 50n, are near the intersection of Sterling Street and Base Line Avenue. Their waters are slightly higher in salinity than those of neighboring wells, 42.9 to 62.6 conductance, and the boron contents are also higher, .16 to .71 ppm. While these waters from the eight wells mentioned are noticeably different in composition from the others of this section, it is not to be inferred that they are unsuited for irrigation use, particularly if conditions are such that they could be blended with those of other nearby wells.

North of Highland Avenue, between Del Rosa Avenue and the channel of Waterman Creek are three wells, Nos. 44f, 34a, and 44g, which appear to be slightly contaminated with boron, having from .42 to .66 ppm of that constituent. In other respects their waters are not unusual, as they range in conductance from 37 to 56.4. Farther west, close to the foothills, wells Nos. 24 and 10 have normal waters with conductances of 37.2 and 35.6, and boron contents of .13 and .08 ppm. On Devil Canyon Creek, just below the gaging station, is a shallow well with water having a conductance of 59.3 and a boron content of .02 ppm.

In that section of the area along the channel of Cajon Creek, north of Mill Street and west of E Street, San Bernardino, 17 wells have been sampled. Their waters are all of low salinity and low boron content. The ranges in composition follow: Conductance, 22.7 to 46.2; boron, .01 to .12 ppm; per cent sodium, 9 to 47; chloride, 2 to 11 ppm; sulphate, 10 to 52 ppm; nitrate, 0 to 4 ppm.

In the quadrangle lying between Mill Street and Highland Avenue, and between Sterling Street and E Street, 19 wells have been sampled, several of which are flowing. These include three located near Del Rosa Avenue, north of Base Line Avenue, to be referred to later. Of the remaining 16 the waters are characteristic of the Area, their ranges of composition follow: Conductance, 22.5 to 39.1; boron, trace to .26 ppm; per cent sodium, 0 to 68; chloride, 2 to 20 ppm; sulphate, 7 to 56 ppm; nitrate, 0 to 10 ppm. The three wells mentioned above, Nos. 45b, 46i, and 46L are located adjacent to No. 46n, described in a previous paragraph. These wells also show evidence of slight boron contamination. The composition ranges are: Conductance, 45.3 to 63.4 ppm; boron, .26 to .37 ppm; per cent sodium, 22 to 61; chloride, 18 to 36 ppm; sulphate, 41 to 159 ppm; nitrate, 1 to 27 ppm. These waters, while showing slight boron contamination, are not regarded as unsuited for irrigation use.

The section of the Area lying between Mill Street and the Santa Ana River contains 18 wells that have been sampled, some of them several times or from various depths. The reason for these extra samplings is that the water of some of these wells has been found to contain boron in concentrations high enough to be possibly injurious in irrigation water. Before discussing the wells in this section in more detail it may be said that the waters of ten of them are like those

of other characteristic wells of the Area, low in salinity and boron, their ranges in composition follow: Conductance, 24.2 to 50.4; boron, .02 to .16 ppm; per cent sodium, 15 to 53; chloride, 2 to 30 ppm; sulphate, 4 to 38 ppm. One of these wells, No. 98e, is mentioned especially because an opportunity was offered, while it was drilling in 1931, to obtain samples from each of 24 successive water-bearing strata to a depth of 1166 feet, or 145 feet below sea level. After drilling, the casing was perforated below 500 feet. The ranges in composition for the 25 samples, including the composite after perforation, follow: Conductance, 30.8 to 45.6; boron, .01 to .14 ppm; per cent sodium, 18 to 76; chloride, 7 to 39 ppm; sulphate, 17 to 77 ppm; nitrate, 0 to 4 ppm.

The remaining eight wells of this section in which boron contamination was indicated are all located south of Central Avenue, extended, and west of Waterman Avenue. It should be added that included within these limits are four other wells in which boron contamination is not indicated. In respect to the contaminated wells it is probably not essential to describe their composition further than to give the conductances and boron concentrations. No. 89b is located close to or on the Bunker Hill Dike at De Sienna Mission Hot Springs. It is 547 feet deep, its water is hot, has a conductance of 59.9 and a boron content of 1.65 ppm. A neighboring well, only 60 feet away and but 200 feet deep, yields cold water; conductance, 35.9; boron, .02 ppm. Well No. 93d, west of E Street, just south of Warm Creek, has been sampled eight times, of which five were taken while drilling. The well is 603 feet deep, perforated 52 to 572 feet. The five successive samples while drilling range in conductance from 33.0 to 41.9 and in boron from .07 to .21 ppm. After drilling and the installation of the pump three other samples were taken. These represent discharges of 5 to 7 cfs. Their conductances range from 39.0 to 40.6 and their boron contents from .37 to .44 ppm.

Well No. 94a is south of No. 93d, between Waterman Avenue and Warm Creek. It is 300 feet deep and its water has a conductance of 51.9 and a boron content of .62 ppm. Well No. 93p is approximately 1500 feet east of No. 93d, its depth unknown. Its conductance 45.5; boron, 1.02 ppm. Well No. 94e is 50 feet south of Dumas Drive and 2675 feet west, of Waterman Avenue. It is 1162 feet deep and perforated to 1125 feet: Conductance, 43.9; boron, 0.56 ppm. No. 94b is 590 feet south of Dumas Drive and 760 feet west of Waterman Avenue. Its depth is not known, its water is hot: Conductance, 48.8; boron, 1.52.

Well No. 98b, together with No. 98c, call for more detailed consideration because they throw some light on the source of boron contamination in this section of the Area. Both are flowing wells, 965 feet deep. Samples taken from them in November, 1930, soon after they were installed contained .81 and .89 ppm of boron. This concentration was regarded as too high for the service for which the water was intended. Both wells had penetrated three successive gravel strata and the owner sought to ascertain the possibility of reducing the boron contamination by excluding the contribution from one or two of these strata. Three successive samples from each well prior to April, 1931, confirmed the finding of the first samples.

In April, 1931, the owner undertook to measure the rate of discharge in each well just above each of the three gravel strata and found that each was contributing freely to the combined flow. He then undertook to collect a sample of water from just above each stratum and below the lowest. This was done by inserting a 2-inch pipe to the proper depth and withdrawing a sample through it.

Well No. 98b had been perforated at 638-656, 722-748, and 772-814 feet. On April 1, samples were drawn from 555, 616, 719, and 799 feet depth. The conductance and boron content of each of these samples is shown in Table 10. The data of this table show that the sample drawn from 719 feet contained more boron than the blended flow above that point, and also that the sample from 799 feet contained much less boron. From these results it is inferred that the boron contamination was coming chiefly from the middle stratum, 722-748 feet.

TABLE 10

The Conductance and Boron Content of Water Samples from Successive Depths of Well No. 98b, Ground Elevation, 997 Feet. April 1, 1933

Perforations depth, feet	Sampled at, feet, depth	Conductance Kx10 ³ at 25°C	Boron ppm
-----	555	42.3	.67
638-656	616	41.9	.65
722-748	719	43.5	.80
772-814	799	40.2	.32

A similar series of samples was drawn from Well No. 98c, for which the results are shown in Table 11. These results show that the sample from 704 feet, the middle stratum, contained the highest boron content, .84 ppm, while the next lower sample at 786 feet, third stratum, contained only .20 ppm, and the lowest sample, 878 feet, representing the contribution through the open bottom of the well contained only .07 ppm. Comparison of the rates of flow at various depths in the wells, not here reported, with the boron concentration of the samples, lead to the conclusion that the boron was contributed chiefly from the middle stratum in which it occurred in concentrations much higher than the .80 ppm found in the composite samples from the well.

TABLE 11

The Conductance and Boron Content of Water Samples from Successive Depths of Well No. 98c, Ground Elevation, 1,002 Feet. April 6, 1933

Perforations depth, feet	Sampled at, feet, depth	Conductance Kx10 ³ at 25°C	Boron ppm
-----	537	44.0	.80
556-638	642	44.9	.82
722-748	704	44.1	.84
772-814	786	39.4	.20
-----	868	38.7	.07

Following the investigation here reported, Well No. 98c was plugged at 485 feet and perforated above that point. Subsequently, four successive samples of the discharge were taken and these had conductances ranging from 28.2 to 31.3 and boron contents ranging from .05 to .31 ppm, a decided improvement in quality as compared with the earlier discharge.

In the section of the Area south of the Santa Ana River and west of Anderson Street (Tippecanoe Street), 12 wells have been sampled. The composition of these samples is similar to that of the other wells of the Area outside of the zones of boron contamination. The concentration ranges are as follows: Conductance, 35 to 71.5; boron, .01 to .40 ppm; per cent sodium, 17 to 91; chloride, 18 to 36 ppm; sulphate, 31 to 85 ppm; nitrate, 3 to 15 ppm. Three of these wells, Nos. 94i, 94j, and 94h, located southwest of the intersection of Colton and Waterman Avenues show very slight evidence of boron contamination, i.e., .31 to .40 ppm.

CHAPTER IX

THE SAN TIMOTEO AREA

This Area includes the drainage basin of San Timoteo Creek, together with three wells and a spring east of Beaumont, and four wells in the city of Redlands. The waters sampled in this Area are all of low to intermediate salinity, the highest conductance being 108 for Well No. 223. The boron content is very low. A few samples contain a high percentage of sodium, and the nitrate content is relatively high. In general, the sulphate exceeds the chloride.

The samples from the foothills north of Beaumont range in conductance from 35 to 40.4. Those from the divide east of Beaumont range in conductance from 20.1 to 93.5, but are very low in sulphate and higher in nitrate. The wells on the high ground between Beaumont and Yucaipa are of low salinity, ranging in conductance from 31.3 to 53.9; these extremes occurring in two wells near Beaumont, No. 241 and 243j.

The nine samples from wells north and west of Yucaipa range from 41.1 to 60.4 with both sulphate and nitrates relatively high. The wells along the main channel of San Timoteo Creek show conductances ranging from 35.6 to 108, with the salinity increasing in the downstream direction. The wells nearest the Badlands south of the creek show relatively high chlorides in comparison with the sulphate as in Nos. 237 and 227d. The four samples from wells in the city of Redlands are of low salinity but contain appreciable quantities of nitrate.

CHAPTER X

THE RIVERSIDE AREA

The Riverside Area lies south of the Santa Ana River between the San Bernardino Area and the Temescal Area. The irrigated lands in this Area receive very little run-off water from the low hills that here mark the boundary between the South Coastal Basin and the contiguous San Jacinto Basin. The irrigation supply is drawn largely from the San Bernardino Area which lies above the Bunker Hill Dike. This is supplemented by a number of wells located within the Area. The water of some of these wells has been found to be too saline for safe use in irrigation and in consequence a large number of analyses have been made of samples from these and adjacent wells during the past 20 years. Many of these analyses have been available for this report.

Underground Waters.

In that part of the area north of the Riverside County line, 17 wells have been sampled. Conductance and boron determinations were made on only two, Nos. 76d and 82, for which the conductances were 60.8 and 68.5 and the boron contents were .07 and .18 ppm respectively. For the whole group the ranges of the other constituents were as follows: Per cent sodium, 15 to 52; chloride, 18 to 221 ppm; sulphate, 24 to 94 ppm; nitrate 3 to 46 ppm. In respect to irrigation use only No. 81b and 71b are in the intermediate class as to chloride, the former having 221 ppm and the latter 156 ppm.

Between the Riverside County line and Columbia Avenue, continued as Santa Ana Street, seven wells have been sampled, for three of which conductance and boron determinations have been reported. The composition ranges for the samples of this group are as follows: Conductance, 34.4 to 73.4; boron, trace to .16 ppm; per cent sodium, 22 to 36; chloride, 6 to 71 ppm; sulphate, 17 to 53 ppm; nitrate, 3 to 13 ppm.

Between Columbia Avenue and Sycamore Canyon, east of La Cadena Drive and Kansas Avenue ten wells have been sampled. Of these, four call for special consideration because of their high chloride content. Two of these, Nos. 201 and 201c, are located on Indianapolis Avenue, west of the intersection with Chicago Avenue. The chloride contents of these were 200 and 225 ppm respectively. The other two, Nos. 202c and 203, are located on Chicago Avenue adjacent to Sycamore Canyon. Their chloride contents were 240 and 232 ppm respectively. Samples from the remaining six wells of this group are of lower salinity; conductances and boron determinations are reported for three of them. Their composition ranges follow: Conductance, 45.9 to 72.2; boron, .04 to .15 ppm; per cent sodium, 18 to 56; chloride, 53 to 119 ppm; sulphate, 19 to 72 ppm; nitrate, 8 to 31 ppm.

In the section west of the one just described, 13 wells have been sampled. The samples of ten of these indicate, with one exception, water of good quality for irrigation use, with the following composition ranges: Conductance, 35 to 82; boron, .04 to .14 ppm; per cent

sodium, 17 to 45; chloride, 11 to 142 ppm; sulphate, 17 to 68 ppm; nitrate, 3 to 8 ppm. The exception noted above is from No. 68i, a hot water having a conductance of 51 but with .70 ppm boron and a sodium percentage of 90. The three remaining wells of this group are located adjacent to the delta of Sycamore Canyon, they are Nos. 202a, 197a, and 197c. These waters, like those from Nos. 202c and 203 higher up the delta, are more saline. Their composition ranges are: Conductance, 98.3 to 124; boron, .12 to .14 ppm; per cent sodium, 32 to 37; chloride, 160 to 271 ppm; sulphate, 28 to 59 ppm; nitrate, 13 to 27 ppm.

South of Sycamore (Tequesquite) Canyon, between the Gage Canal and Magnolia Avenue, and extending to Van Buren Street is a section in which the underground waters are remarkably saline for the South Coastal Basin. Thirteen wells have been sampled, some of them repeatedly since 1916. These waters are characterized by high chlorides and relatively high nitrates. Conductances and boron have been determined on only three of the more saline wells, but the concentrations of the other constituents leave no room for doubt that the underground waters of this section are and long have been very saline. Four of these 13 wells are located on the delta cone of Mockingbird Canyon, adjacent to Jackson Street. It appears that conditions in that delta cone may have been modified in recent years possibly in consequence of the existence above it of a storage reservoir, a part of the Gage Canal System. The waters of these four wells will be discussed later.

The nine wells located in the part of this section northeast of the delta of Mockingbird Canyon, i.e., between Monroe Street and Arlington Avenue, are mostly 150 to 300 feet deep, and are in an area of highly developed agriculture served by canals of the Gage and Riverside water companies with water imported from the San Bernardino Basin. The conductances and boron contents of three of the wells range from 167 to 219, and from .22 to .24 ppm. The ranges for the other constituents for all nine wells are as follows: Per cent sodium, 16 to 54; chloride, 334 to 582 ppm; sulphate, 49 to 206 ppm; nitrate, 20 to 141 ppm. The chloride concentrations of these waters are so high as to make their use for irrigation hazardous.

All of the four wells referred to above as located on the delta cone of Mockingbird Canyon are much less saline than those discussed in the previous paragraph. No. 183a, at 900 feet elevation, is 127 feet deep. It has been sampled three times since 1925 and its chloride content has ranged from 37 to 54 ppm. No. 183, at the same elevation is 115 feet deep. It was sampled in 1918, when its chloride content was 115 ppm, and again in March, 1933, when its conductance was 70.1 and its chloride content was 76 ppm. Well no. 181 (two connected wells 124 and 160 feet deep), located at 790 feet elevation was sampled in February, 1932, and found to have a conductance of 73.8, a boron content of .16 ppm and a chloride content of 80 ppm. Well No. 182a differs from the other three of these delta-cone wells. It is located at 835 feet elevation, is 421 feet deep, and said to reach to the granite floor of the valley. Its water is hot, 35°C, has a conductance of 59.5; boron, .44 ppm; per cent sodium, 91; chloride, 98 ppm; sulphate, 70 ppm; nitrates, none. This hot, soft water is very different in character from the other waters in this neighborhood.

In the section west of Magnolia Avenue to Van Buren Street, north of Arlington Avenue, seven wells have been sampled. Four of these, Nos. 178a, b, d, and e, are located near the intersection of Central Avenue with Leach Street, at 780 feet elevation. The deepest one is 117 feet. Their composition ranges are: Conductance, 129 to 149; boron, .20 to .28 ppm; per cent sodium, 35 to 49; chloride, 160 to 227 ppm; sulphate, 41 to 83 ppm; nitrate, 18 ppm. While these waters are less saline than those found farther west, they are more saline than the characteristic waters of the Santa Ana Basin. Wells Nos. 177a and 170 are slightly less saline; conductances 118 and 123, while No. 170a, a shallow well located close to the Santa Ana River, has a conductance of 89.5 and in other respects is similar to that of the river water at that point.

In the triangular section of the area bounded by Arlington and Magnolia Avenues and Van Buren Street, 13 wells have been sampled. The ground surface in this section is nearly level at 750 feet elevation and the underground water is generally less than 20 feet below the surface. Nine of the 13 wells have chloride contents of 142 ppm or more, ranging up to 500 ppm. There are no very clear trends of salinity in the section. Some of the high salinity in shallow wells may be the result of concentration due to surface evaporation from low areas where the underground water comes up into the root zone. One well, No. 180, has a very low conductance of 49.4 with only 66 ppm chloride. Another, No. 174e, on the front of the delta cone of Mockingbird Canyon, has a conductance of 90.5 with 98 ppm chloride, a composition similar to that of the nearby Well, No. 181.

In the section west of Van Buren Street to Holden Avenue and northwest of Magnolia Avenue to the Santa Ana River, 11 wells have been sampled. Here also the trends of salinity are not well defined. Five of the 11 wells have chloride contents below 142 ppm, with correspondingly low conductances where these determinations have been made. For the remaining six wells, Nos. 160, 164d, 164e, 164f, 167 and 168, the composition ranges are as follows: Conductance, 121 to 251; boron, .16 to .43 ppm; per cent sodium, 29 to 56; chloride, 220 to 446 ppm; sulphate, 51 to 171 ppm; nitrate, 18 to 75 ppm.

In the section south of Magnolia Avenue to Victoria Avenue, between Van Buren and Taylor Streets, 12 wells have been sampled. In general the salinity is much less in this section than it is to the north and east. In only three of the 12 wells is the chloride content more than 142 ppm, and in one of these, No. 176e, it is 160 ppm. The two most saline wells are Nos. 169b and 169h, in which the chloride concentrations range from 215 to 298 ppm. One of the wells in this section calls for special mention. It is No. 176d, known locally as Beulah Spring. Its water is hot and has a composition very similar to that of Well No. 182a, mentioned in a previous paragraph. The conductance of both waters is 59.5; the boron contents are .44 and .50 ppm; the per cent sodium, 89 and 91, and the chlorides, 98 and 101 ppm. This similarity in temperature and composition of two wells located one and a quarter miles apart is regarded as very striking.

In the section southwest of Taylor Street and Holden Avenue, on both sides of Magnolia Avenue, 11 wells have been sampled. Here also

the salinity is not high, only three of the 11 wells having chloride concentrations above 142 ppm. These are Nos. 298, 298a, and 304c. The highest conductance of these is 167 and the highest chloride content is 243 ppm. These three wells are very close to the southwest boundary of the Area.

In that part of the area southeast of the Gage Canal and between Sycamore Canyon and Mockingbird Canyon the topography is rough and the land for the most part nonarable. It includes the drainage of the north slope of the low hills that divide the Riverside Area from the Perris Valley. Samples of water were collected from this section of the Area primarily with the view of obtaining information as to the source of the salinity that occurs in the underground waters of the irrigated lands between Sycamore Canyon and Mockingbird Canyon. Well Nos. 218 and 349, located adjacent to the Box Springs Road, are of low salinity, conductances, 59.8 and 85.4; boron, .07 and .10, and chloride, 115 and 158 ppm. Wells 339 and 339a, located on Wood Road at elevation 1585 and 1630 feet are likewise of low salinity, conductance, 131 and 44.9; boron, .15 and .14 ppm; chloride, 290 and 55 ppm. Farther east, also on high ground, is well No. 329 at 1585 feet elevation, with conductance, 63.5; boron, .14 ppm, and chloride, 80 ppm.

North of this well and on lower ground in the vicinity of Bradley Street, elevations 1025 to 1160 feet, are five wells, Nos. 195, 195a, b, c, and 200. Two of these, 195a and 195c, have low salinity; chloride, 114 and 155 ppm. Two others, Nos. 195 and 200, are slightly more saline; chloride, 383 and 273 ppm. The last, No. 195b, is a shallow well, 50 feet deep, with a chloride content of 1597 ppm.

Along Mockingbird Canyon seven samples have been obtained including one from Mockingbird Spring, S16124. These samples are all of low to intermediate salinity, ranging in chloride content from 115 to 213 ppm. It is evident then that with the possible exception of Well No. 195b, none of the waters reported for this section of the hills south of the Gage Canal can be taken to represent the source of the contamination found in the waters north of that canal. In a subsequent chapter some of the possible sources of that contamination will be discussed.

CHAPTER XI

THE TEMESCAL AREA

The Temescal Area includes the delta cone of Temescal Creek in the neighborhood of Corona, and the drainage area of that stream, including that of Cajalco Creek, its chief tributary from the east. In this chapter the discussion will be limited to the lower portion of the Area lying north of the mouth of Cajalco Canyon. Conditions along Cajalco Creek are discussed in Chapter XII on the sources of contamination in the Riverside and Temescal Areas. The irrigation supplies for the Temescal Area are drawn largely from local underground sources but have been supplemented from time to time from outside sources. As early as 1890 some water was imported from Lake Elsinore, but its salinity made it unsatisfactory for irrigation use. Subsequently some water has been imported from wells located in the San Jacinto Basin, southeast of Perris, and also from the San Bernardino Basin. Some natural contributions to the Area have occurred in the past by the overflow of Lake Elsinore into Temescal Creek, as in 1916.

Underground Waters.

In that section of the Area lying south of Magnolia Avenue, extended, and of Ontario Avenue, 12 wells have been sampled, but boron determinations are reported for only two of them, Nos. 294b and d, and nitrate for only the first named. The composition ranges are as follows: Conductance, 77 to 158; boron, .22 to .25 ppm; per cent sodium, 7 to 44; chloride, 28 to 188 ppm; sulphate, 30 to 445 ppm; nitrate, 21 ppm. It will be observed that the sulphate concentration ranges higher than the chloride. This condition is most pronounced in Wells 277b, 278, 285, and 297a, all of which are located close to the base of the Santa Ana Mountains.

The section north of Magnolia Avenue and east of the city limits of Corona contains five wells that have been sampled but boron and nitrate were not determined. These are all located on low ground, elevations 608 to 667 feet. Their composition ranges follow: Conductance, 121 to 172; per cent sodium, 39 to 48; chloride, 153 to 305 ppm; sulphate, 91 to 129 ppm. Here the chloride concentrations range above the sulphate and this is true for each sample.

Within the city limits of Corona, south of The A. T. and S. F. Railway, 12 wells have been sampled, but boron was determined for only two samples from one well, No. 274c, and nitrates for only four wells. The composition ranges are: Conductance, 81 to 152; boron, .14 to .20 ppm; per cent sodium, 16 to 43; chloride, 66 to 217 ppm; sulphate, 87 to 192 ppm; nitrate, 8 to 26 ppm. The only noticeable trend of salinity in this section is that the lowest salinity is found in the wells near its western limit, particularly in Nos. 273a and 274c.

In the section west of the city limits of Corona and south of The A. T. and S. F. Railway, 14 wells have been sampled, but no boron or nitrate determinations are reported. The waters of this section are of low salinity for this Area. The composition ranges are: Conductance, 95 to 116; per cent sodium, 9 to 35; chloride, 28 to 121 ppm; sulphate, 100 to 289.

Between The A. T. and S. F. Railway and the channel of Temescal Creek, west of the city limits is a section in which 13 wells have been sampled, but boron and nitrate determinations have not been reported. In general the salinity is slightly higher in this section than in the one south of the railway. These wells are on low ground, 484 to 540 feet elevation, and most of them are shallow; the deepest being 150 feet. Their composition ranges are: Conductance, 96 to 194; per cent sodium, 31 to 53; chloride, 57 to 287 ppm; sulphate, 84 to 143 ppm. The lowest salinity is found in Wells 267 and 267e, in the western end of the section.

In the section included within the city limits north of The A. T. and S. F. Railway, 13 wells have been sampled but the boron content, .34 ppm, is reported for only one, No. 286b, and the nitrate for only three, Nos. 280a, 282, and 286b. The composition ranges are: Conductance, 121 to 227; per cent sodium, 25 to 58; chloride, 174 to 372 ppm; sulphate, 86 to 208 ppm; nitrate, 4 to 22 ppm. One sample from Well No. 280a, collected in September, 1918, appears to have shown an abnormal composition; its chloride content was reported as 30 ppm and its sulphate as 369 ppm. Another sample taken the same month was found to contain 176 ppm chloride and 109 ppm sulphate. In general the waters of this section are of relatively high salinity.

In the section between the channel of Temescal Creek and the Auburndale road, northwest of the city limits, 15 wells have been sampled but the boron and nitrate contents were determined on only one of them, No. 151j. Their composition ranges are: Conductance, 64 to 250; boron, .45 to .53 ppm; per cent sodium, 11 to 65; chloride, 60 to 369 ppm; sulphate, 20 to 122 ppm; nitrate, 8 to 9 ppm. Six of the wells in this section are of low salinity. They are Nos. 148, 149j, 150, 150b, 151d, and 151b. All but the last named are the most northerly wells in the section; i.e., the farthest from Temescal Creek.

In the section northeast of Auburndale road and north of the city limits, 11 wells have been sampled. The boron content is reported for none and the nitrate for only one, No. 153j. The composition ranges are: Conductance, 69 to 210; per cent sodium, 37 to 55; chloride, 100 to 480 ppm; sulphate, 38 to 231 ppm; nitrate, 45 ppm. The highest salinity occurred in Wells 154 and 154d, and the lowest in Well No. 153k, which is located nearby.

In respect to the Temescal Area as a whole, its underground waters are in some places of high chloride salinity as in the Riverside Area. It seems possible that the source of that salinity is the same for both areas. Furthermore, it seems probable that it is the salinity from these two areas that contributes chiefly to the salt burden on the Santa Ana River as it enters the lower canyon.

CHAPTER XII

SOURCE OF SALINITY IN RIVERSIDE AND TEMESCAL AREAS

It has been pointed out in the discussion of these two Areas that there occurs in each some underground water of high chloride salinity. Elsewhere in the Upper Santa Ana Basin the chloride content of the underground water is generally low and this is true also for the surface water contributed from the higher watershed. It seems appropriate, therefore, to look elsewhere for the source of the salinity that occurs in these two Areas and that is contributed from them to the Santa Ana River.

In respect to the Temescal Area, it has been shown that most of the higher chloride salinity occurs in wells located along the channel of Temescal Creek, above its junction with the Santa Ana River. It seems probable that this salinity may have come in by way of the creek in former years when Lake Elsinore overflowed its natural barrier and discharged into it. The water of Lake Elsinore is known to be of high chloride salinity. Its concentration varies inversely with its volume because the flood waters of San Jacinto River, its chief tributary, are of relatively low salinity. It is probably not essential to the present inquiry to review all of the available analytical data as to the varying salt content of the Lake water. During the past three years the lake has been low and its salinity consequently high. Three samples, taken in September and November, 1931, and in April, 1932, have the following composition ranges: Conductance, 540 to 697; boron, 2.03 to 2.73 ppm; per cent sodium, 95 to 97; chloride, 1172 to 1526 ppm; sulphate, 206 to 276 ppm; nitrate, none. Water of this salinity, even if diluted by river inflow to such a volume that the Lake would overflow its barrier and discharge into Temescal Creek, would probably account for the salinity conditions found in the delta of the creek.

Owing to the lack of information to the contrary it is assumed that the salinity now found in Lake Elsinore has been contributed thereto by the San Jacinto River either from its upper watershed or from the Perris Valley which it drains. There is only scanty information concerning the quality of the water of the river as it leaves the mountains but such as there is indicates that it is of low salinity like that of the streams of the Upper Santa Ana Basin. The channel as it crosses the main basin to Railroad Canyon is dry much of the time. The underground waters of the San Jacinto Basin have been investigated¹ and the findings show that they are highly saline in several places. Thus it may be inferred that the salinity now found in Lake Elsinore may have originated in the San Jacinto Basin either as the result of evaporation and concentration while the Basin was filling with sediment or from magmatic sources possibly through fault fissures of which there are at least two, the San Jacinto and the Elsinore.

While there is a fair basis for the inference that the chloride salinity found in the Temescal Area may have come from the San Jacinto Basin by way of Lake Elsinore and Temescal Creek, the source

¹Waring, Gerald, A. Ground water in the San Jacinto and Temecula Basins, California; Water Supply Paper 429; U. S. Geol. Surv. 1919.

of that found in the Riverside Area is not so clear. Some consideration has been given to the possibility that this latter salinity may have originated locally. It is possible that the deeper sediments of the section adjacent to the low hills south of Riverside may have been deposited as an ancient playa in which evaporation and concentration occurred. The evidence to support this hypothesis is not convincing. It may be that the rock mass of these hills or the soils that have weathered from it contain soluble salts, largely chlorides. The geological view, currently accepted, is that the rock mass of these hills is essentially granitic, similar in composition to that of the mountains to the north. In general this rock mass has only a thin cover of soil. It seems improbable that this granitic rock or the soil weathering from it would yield any large quantity of chloride salinity here and not elsewhere in the Basin.

It was remarked in the discussion of the Riverside Area that while high salinity was found in the underground waters at the base of the hills from Sycamore Canyon south, samples from a few wells at higher elevations did not show such salinity. Toward the crest of these hills there is a shallow trough, with an east-west axis, drained by Cajalco Creek, a tributary of Temescal Creek. The channel of Cajalco Creek is normally dry except at occasional places where water in small volume comes to the surface only to disappear again in a short distance. The watershed is of small extent and in the upper part of the Basin the topography is gentle and much of the land is arable.

In the Cajalco basin 28 wells and 6 springs have been sampled; of these, 11 wells and 2 springs are classed as of low salinity having conductances, when determined, of less than 100 and chloride contents of 142 or less. Five wells and 2 springs are classed as of intermediate salinity, i.e., with conductances of more than 100 but less than 355 ppm. These waters may be dismissed from further consideration in the present connection because their salinity is not higher than might be expected for such conditions and such waters could not be regarded as the source of the salinity in question.

There remains to be considered 12 wells and 2 springs or seepages of high salinity. The two seepage waters, S16156 and S16156A, are from the channel of Cajalco Creek and from the bank of the channel nearby. Their respective compositions follow: Conductance, 356 and 403; boron, .16 and .17 ppm; per cent sodium, 50 and 51; chloride, 819 and 914 ppm; sulphate, 390 and 426 ppm; nitrate, trace and 1 ppm. Of the group of 12 wells classed as highly saline, conductance and boron have been determined for only one, No. 337, in which the conductance is 212 and the boron is .08 ppm. This well is classed as of high salinity because the chloride content is 475 ppm. The well, a shallow one, is located near to the two seepages described above and these three samples are from the section highest upstream of any of this saline group, elevation 1550 feet. The next well in the downstream direction is No. 337a, at 1540 feet, also a shallow well with 620 ppm chloride. Then follows Nos. 332e, 327, and 326, at 1475 down to 1400 feet, with chlorides ranging from 485 down to 390 ppm. Still farther down are seven wells, 326a, 322a, b, c, and d, 317b, and 316c. They are all shallow wells, near the stream channel, at elevations from 1395 down to 1290 feet. Their chloride contents range from 400 to 990 ppm.

The quality of the waters from these 14 locations along Cajaleo Creek within a distance of $5\frac{1}{2}$ miles is regarded as possibly of significance in connection with the high salinity of the Riverside Area. The thought here suggested is that there may be some relationship between the source of the salinity appearing in the channel of Cajaleo Creek at Location S16156 and that found in the Riverside Area adjacent to the hills on which the basin of Cajaleo Creek lies. It seems probable that the high salinity found in the shallow wells close to the stream channel below this location may be due to salts carried down stream from this point.

As a common source for the salinity found in the San Jacinto Basin, in Cajaleo Creek, and in the Riverside Area, it is natural to suggest that the homogeneous character of the granite block composing these hills may be altered along a zone running in the northwest-southeast direction, crossing Cajaleo Creek in the vicinity of Location S16156. There are certain topographic features to be noted in support of that suggestion. These may be enumerated as follows: (1) Such a zone would be approximately parallel with and intermediate between the San Jacinto Fault and the Elsinore Fault. (2) It would coincide with Mockingbird Canyon. (3) It would cross the Santa Ana River at the point where that stream changes its direction north of La Sierra Heights. (4) It would lie under that part of the San Jacinto Basin known as Meniffee Valley in which some of the underground waters are known to be of high chloride salinity. Finally, it would pass under the Riverside Area between Wells 182a and 176d, mentioned in the discussion of that Area, in which the waters are hot and have other characteristics different from those of neighboring wells.

In reference to the suggestion made in the preceding paragraph, Mr. Rollin Eckis makes the following comment:

The bedrock south of Riverside, separating the Perris and Riverside alluvial basins is, in the main, granitic. Locally, patches of schist and gneiss occur. Areas of basic igneous intrusive rocks (gabbro and diorite) occur also.

The bedrock is characterized by steeply dipping schistose or gneissic structure (alignment of the mineral grains) that trends generally about N. 35° W. There are local exceptions to this trend. The schistosity noted is particularly well developed in a zone one to two miles wide that enters the Riverside basin at the mouth of Mockingbird Canyon. Within this zone gneissic banding is very prominent. The zone can be traced southeast for many miles, and is characterized by numerous patches of schist, gneiss, gabbro, etc., all of which conform to the general trend.

The schistose structure in the bedrock does not indicate faulting. It is a crystalline structure produced by stresses acting at a time when the rocks were deeply buried and in a plastic condition.

This schistosity undoubtedly extends to great depths, and does therefore probably afford an avenue for the upward movement of deep-seated waters and gases along planes of schistosity. Local shearing has probably occurred along some of these planes and has thus facilitated the movement of waters and gases upward along them.

There is no continuous fault or shear zone along the line of Mockingbird Canyon; in fact faults of any importance are remarkably rare. It does not seem probable that any important fault zones connect the Riverside and Perris basins. The absence of such fault zones appears to obviate the possibility of lateral migration of the waters from one basin to the other. Furthermore, many springs and other evidences of high groundwater levels between the two basins clearly show that there is no lateral migration of water from one basin to the other. It seems distinctly possible, however, that deep-seated waters and gases may percolate upward from the same general source into both the Riverside and the Perris basins.

Dr. F. L. Ransome made a detailed geological study for the Metropolitan Water District of the area, in connection with the proposed Val Verde tunnel line. His geological map shows lenses of schist and basic igneous rocks along the Mockingbird Canyon line of schistosity, but shows no faults. In fact, he states in the text of his report that he considers this granitic area between Perris Valley and Cajaleo to be one of the most solid blocks of the earth's crust to be found anywhere in southern California.

In view of these findings the inference seems warranted that the high salinity found in the underground waters of the Riverside Area may have come from deep magmatic sources either in waters or as gases, such as hydrochloric acid gas, finding their way upward through this schistose zone of the granitic intrusion. Furthermore, this or similar zones may have afforded the pathway of similar salinity found in the sediments of the San Jacinto Basin, from which it has been carried into Lake Elsinore and finally into the Temescal Area.

CHAPTER XIII

THE LOS ANGELES DISTRICT

This district includes three areas, the Los Angeles, the Venice, and the Redondo-Long Beach. It is bounded on the north by the San Fernando Area, on the east by the upper and lower San Gabriel Areas, and on the south and west by the Pacific Ocean. It includes the drainage of the Los Angeles River after that stream leaves the San Fernando Area and the drainage areas of Ballona Creek and other small streams from the Santa Monica Mountains as far west as Topanga Creek. Ballona Creek drains the north and east slopes of Baldwin Hills and the south slope of the Santa Monica Mountains, passing through the Venice Area to the ocean. Centinela Creek drains the south slopes of Baldwin Hills north of Inglewood and passes out through the Venice Area. Nigger Slough drains the Redondo-Long Beach Area between the San Pedro Hills and the Inglewood Fault line, discharging into San Pedro Bay. Compton Creek drains the Area between the Inglewood Fault and the Los Angeles River.

The Los Angeles River enters the district through a narrow valley between the Santa Monica Mountains and the San Rafael Hills. At this point its channel elevation is 300 feet, or 135 feet lower than its elevation at the junction of Verdugo Creek at the southeast corner of San Fernando Valley, and 100 feet higher than at the head of the delta cone near Vernon. Through this section the channel has a fall of 20 feet to the mile and carries little water except at flood time. From the head of the delta cone to the ocean the channel gradient is less steep, about 10 feet to the mile.

Records of wells located in the canyon section of the Los Angeles River show the elevation of the underground water in that section. Those at the junction of Arroyo Seco show water at about 300 feet elevation or close to the ground surface. About one and a quarter miles downstream, near the intersection of Avenue 20 with Main Street, it stands at 283 feet, and on the west side of the channel, between Macy and Aliso Streets, it stands at 248 feet, in both cases within 10 to 20 feet of the ground surface. Within the next mile downstream wells at 4th and Alameda Streets show the water level to be at 157 feet, or more than 100 feet below the ground surface. A mile and a half farther downstream, east of the channel, near the intersection of 9th and Soto Streets, the water stands at 105 feet or 150 feet below the ground surface. This rapid fall in the elevation of water levels of 143 feet in the two miles between Aliso and 9th Streets indicates the existence of an underground barrier crossing the channel in this section. A similar contrast in water elevations exists two and a half miles east of the river channel. A well just southeast of the intersection of Brooklyn and Rowan Avenues has water at 218 feet elevation, while in a well one mile south, near the intersection of Whittier Boulevard and Eastman Street, it stands at 89 feet.

THE LOS ANGELES AREA

The Los Angeles Area is one of the three subdivisions of the District of the same name. On the north it is conterminous with the San Fernando Area. On the east its boundary follows the drainage divide between the Los Angeles and San Gabriel Rivers, crossing Arroyo Seco west of South Pasadena, to the Rio Hondo at Whittier Narrows, thence down the channels of the Rio Hondo and the Los Angeles River to the point where the channel of the latter crosses the Inglewood Fault line. The western boundary of the Area follows the Inglewood Fault line to Baldwin Hills, thence in a northwesterly direction, west of Beverly Hills, to intersect the northern boundary of the Area.

Surface and Subsoil Waters.

The quality of the flood waters entering this Area by way of Arroyo Seco and the Los Angeles River is shown by two samples from the first named stream, taken in January, 1933, at the gaging station at Avenue 26, and by three samples taken from the latter named stream at the gaging station at Dayton Avenue bridge. The ranges in composition for all five samples, based on partial analyses, are as follows: Chloride, 11 to 83 ppm; sulphate, 4 to 74 ppm. The highest discharges represented by these samples taken during this January flood period, 1933, were 200 cfs in the Arroyo Seco and 4000 cfs in the Los Angeles River. During the same flood period, but not on the same days, samples were taken from the Los Angeles River at three points downstream from the Dayton Avenue bridge: one at Location S2774, elevation, 250 feet; three at Location S1525, elevation, 95 feet; and one at Location S895, elevation, 40 feet. The discharges at these points at the time of sampling ranged from 150 cfs to 2000 cfs. The composition ranges for the five samples are: Conductance (one only), 28; chloride, 11 to 64 ppm; sulphate, 33 to 163 ppm; nitrate, 0 to 7 ppm. On March 24 and April 11, 1932, individual samples were taken from the river at Locations S1524, S1525, and S911, at elevations 105, 95, and 56 feet respectively, when the discharges were very low; i.e., 0.3 and 1.4 cfs in the two cases reported. The composition ranges of these are: Conductance, 54.3 to 102; boron, .19 to .65 ppm; per cent sodium, 49 to 60; chloride, 6 to 105 ppm; sulphate, 44 to 163 ppm; nitrate, 0 to 2 ppm. Another sample taken on December 17, 1932, at Location S2777, elevation 210 feet, discharge, not reported, contained 54 per cent sodium, 226 ppm chloride, and 247 ppm sulphate.

Compton Creek was sampled at Location S871, elevation 65 feet, on February 15, 1932; the discharge is not reported and the sample contained 23 ppm chloride. A sample from the same creek taken on January 25, 1933, at Location S883A, elevation 50 feet, discharge 40 cfs, contained 21 ppm chloride and 28 ppm sulphate. The summer condition of this creek water as sampled on July 22, 1932, at Compton Pond, Location S883, elevation 46 feet, was: Conductance, 175; boron, not determined; per cent sodium, 52; chloride, 344 ppm; sulphate, 222 ppm; nitrate, trace.

The Rio Hondo, as sampled on January 19 and 29, 1933, at Location S1535, elevation 95 feet, discharge, 400 and 600 cfs, contained 14 ppm of chloride in both cases and 11 and 13 ppm sulphate.

The subsoil waters of the area are represented by 3 samples. One of these is from a spring at Location S2627 on the north slope of Baldwin Hills at elevation 50 feet, sampled March 25, 1932: Conductance, 1403; boron, 4.94 ppm; per cent sodium, 52; chloride, 4083 ppm; sulphate, 1880 ppm; nitrate, none. The other 2 samples, taken in February and March, 1932, are from test holes. One, No. 73e, is in the north edge of Lynwood and the other, No. 116m, is in Compton. Their respective compositions are: Conductance, 336 and 157; boron, .83 and .38 ppm; per cent sodium, 61 and 42; chloride, 417 and 181 ppm; sulphate, 672 and 185 ppm; nitrate, 2 and 6 ppm.

Underground Waters.

In the section of the Area north of Wilshire Boulevard and west of the Los Angeles River 5 wells have been sampled. The analyses for 4 of them are complete while that of one, No. 6i, includes only chloride and sulphate. The composition ranges are: Conductance, 64.8 to 119; boron, .05 to 1.01 ppm; per cent sodium, 32 to 67; chloride, 36 to 200 ppm; sulphate, 27 to 162 ppm; nitrate, 0 to 6 ppm. The highest conductance and sulphate occur in No. 21b, the highest boron and per cent sodium in No. 11f, the highest chloride in No. 6i, and the highest nitrate in Nos. 14 and 11f.

In the section east of the Los Angeles River and north of Whittier Boulevard 5 wells have been sampled. Three of these are of low salinity as follows: Conductance, 50 to 77.9; boron, .16 to .41 ppm; per cent sodium, 45 to 81; chloride, 39 to 106 ppm; sulphate, 23 to 58 ppm; nitrate, 0 to 6 ppm. The other 2 wells, Nos. 803w and 803v, are located at the east foot of Montebello Hills and are more saline. No. 803v has been sampled 11 times; the composition ranges for these 2 are: Conductance, 128 to 220; boron, .66 to .95 ppm; per cent sodium, 46 to 52; chloride, 268 to 564 ppm; sulphate, 21 to 35 ppm; nitrate, none. The highest per cent sodium in this group occurs in No. 806d.

South of Whittier Boulevard, between the Rio Hondo and the Los Angeles Rivers, 9 wells have been sampled of which all but one, No. 834m, are of low salinity. The composition ranges of the 8 are: Conductance, 40.9 to 89.4; boron (5 only), .07 to .16 ppm; per cent sodium, 16 to 41; chloride, 25 to 124 ppm; sulphate, 16 to 128 ppm; nitrate, 1 to 14 ppm. Well No. 834m has water of high salinity, a fact confirmed by the analysis of 2 samples, one taken in July, 1931, and the other in February, 1933. The composition of the latter was: Conductance, 257; boron, .17 ppm; per cent sodium, 29; chloride, 387 ppm; sulphate, 597 ppm; nitrate, 4 ppm.

West of the Los Angeles River to Alameda Street, between 7th Street on the north and Imperial Highway on the south, 21 wells have been sampled. These are all of low salinity, with the following ranges in composition: Conductance (6 only), 56.7 to 125; boron (1 only), .24 ppm; per cent sodium (6 only), 24 to 29; chloride, 21 to 69 ppm; sulphate, 20 to 184 ppm; nitrate (6 only), 0 to 133 ppm. Well No. 70 has the highest concentration in respect to all constituents except per cent sodium, in which it is the lowest.

In the section between Alameda Street and Western Avenue, and between Wilshire Boulevard and Imperial Highway, 6 wells have been sampled. All are of low salinity with the following composition ranges: Conductance, 48.8 to 111.8; boron (2 only), .11 and .14 ppm; per cent

sodium, 18 to 37; chloride, 23 to 75 ppm; sulphate, 58 to 165 ppm; nitrate, 0 to 35 ppm. No. 55b is highest in conductance, sulphate, and nitrate.

The section west of Western Avenue and south of Wilshire Boulevard includes the headwaters of Ballona Creek and the eastern slopes of Baldwin Hills. In this section 24 wells have been sampled. Of these 15 are classed as of low salinity with the following composition ranges: Conductance (4 only), 51 to 102; boron (4 only), .09 to .31 ppm; per cent sodium (4 only), 26 to 52; chloride, 21 to 131 ppm; sulphate (12 only), 12 to 129 ppm; nitrate (5 only), 0 to 4 ppm. Three other wells in this section, Nos. 12d, 12u, and 16 are classed as of intermediate salinity with the following composition ranges: Conductance, 141 to 190; boron, .14 to .63 ppm; per cent sodium, 18 to 61; chloride, 160 to 355 ppm; sulphate, 1 to 141 ppm; nitrate, 2 to 7 ppm. One other well, No. 42b, might possibly have been classed as of intermediate salinity but is now of low salinity and merits comment. It was first drilled to a depth of 1097 feet and perforated at 1047 to 1087 feet, from which stratum the water was dark amber in color with a conductance of 201, with 1266 ppm bicarbonate; per cent sodium, 93; chloride, 66 ppm; sulphate, 18 ppm. The casing was subsequently sealed at 321 feet and perforated from 244 to 285 feet, after which the water contained only 36 per cent sodium; bicarbonate, 225 ppm; chloride, 2 ppm; and sulphate, 35 ppm. The 5 remaining wells in this section are all of high salinity. Four of them, Nos. 13e, e, g, and h, located on the north slope of Baldwin Hills in the neighborhood of the spring (Location S2627) mentioned in an early paragraph, while the other, No. 6k, is located farther northwest, near the south edge of the city limits of Beverly Hills. It is inferred that the high salinity of these wells and of the spring is due to the existence of oil wells in the vicinity. Their composition ranges are: Conductance, 469 to 1477; boron, .45 to 1.21 ppm; per cent sodium, 20 to 58; chloride, 650 to 5414 ppm; sulphate, 30 to 171; nitrate, none.

In the section south of Imperial Highway 14 wells have been sampled, all are of low salinity with the following composition ranges: Conductance, 47 to 76.7; boron (1 only), .06 ppm; per cent sodium, 28 to 53; chloride, 20 to 46 ppm; sulphate, 0 to 127 ppm; nitrate, 0 to 1 ppm. The sample here reported for Well No. 117 contained no sulphate, in which respect it resembles samples from other deep wells in the lower part of the Redondo-Long Beach Area. Another sample taken from this well in June, 1931, was reported as containing 1335 ppm chloride in contrast with the 53 ppm in the sample of February, 1933.

There appears to be two sections in this Area in which high salinity and high boron occur in the underground waters. One is adjacent to the Baldwin Hills and the other is adjacent to the Montebello Hills near Whittier Narrows. Otherwise, the waters are of low salinity with the exception of 1 well, No. 834m, located near the channel of the Los Angeles River, southeast of Bell.

THE VENICE AREA

The Venice Area is one of the subdivisions of the Los Angeles District. It lies along the Pacific Ocean west of the Los Angeles Area. It is bounded on the north by the drainage divide of the Santa Monica Mountains and on the south by a line along the crest of the north end of the palisades of the Redondo-Long Beach Area. It includes essentially the delta plain of Ballona Creek and the drainage area of Sepulveda Creek. In general the plane of the underground waters in this area is below sea level, indicating that replenishment from the east is impaired by an underground barrier along the line of the Inglewood Fault. East of this fault line, as in Wells 12 and 12a, underground water stands some 50 feet above sea level.

The only information available as to the quality of the surface water of this area is based on a single sample taken from Ballona Creek at the Duquesne Street crossing, elevation 55 feet, in August, 1931, when the discharge was 3 cfs. Ordinarily the summer flow of the stream is absorbed at about this point, but following storms it carries surface drainage from the western part of the city of Los Angeles. The composition of the sample follows: Conductance, 193.5; boron, not determined; per cent sodium, 59; chloride, 350 ppm; sulphate, 201 ppm; nitrate, 6 ppm.

Underground Waters.

In the section of the area north of Pico Boulevard, 2 wells, Nos. 1a and 4f, have been sampled and show the following compositions respectively: Conductance, 94.5 and 93.6; boron, not determined; per cent sodium, 19 and 21; chloride, 50 and 48 ppm; sulphate, 127 and 212 ppm; nitrate, 40 and 2 ppm.

In the section south of Pico Boulevard to Venice Boulevard and west of Centinela Avenue, 7 wells have been sampled. Two of these, Nos. 5d and 5j, are of low salinity with only partial analyses. Chloride range: 46 to 84 ppm; sulphate (1 only), 92 ppm. Three are classed as of intermediate salinity as follows: Conductance (2 only), 110 to 153; boron (1 only, No. 5h), .22 ppm; per cent sodium (2 only), 24 and 25; chloride, 119 to 276 ppm; sulphate, 130 to 255 ppm; nitrate, 0 to trace. The remaining 2 wells, Nos. 5a and 5e, are of high salinity, judged from partial analyses, having: Conductance, 359 to 473; boron, .18 to .37 ppm; chloride, 916 to 1260 ppm. These 2 wells are reported as not in use; the samples were taken from the bottom of the well in each case.

In the section east of Centinela Avenue, also between Pico and Venice Boulevards, 11 wells have been sampled. All of these are of low salinity, with the following composition ranges: Conductance (3 only), 53.3 to 83.3; boron (1 only, No. 10p), .16 ppm; per cent sodium (2 only, Nos. 7f and 10i), 29 and 23; chloride, 38 to 76 ppm; sulphate, 50 to 150 ppm; nitrate, (2 only, Nos. 7f and 10i), 4 ppm.

In the section south of Venice Boulevard and east of Centinela Avenue, 7 wells have been sampled. Four of these are of low salinity, with the following composition ranges: Conductance, 92.4 to 95.4; boron (2 only, Nos. 10n and 25a), .08 and .06 ppm; per cent sodium, 24 to 26; chloride, 38 to 78 ppm; sulphate, 131 to 184 ppm; nitrate,

0 to 2 ppm. The other 3 wells, Nos. 13f, 25b, and 29b, are of intermediate salinity. composition ranges: Conductance, 117 to 232; boron, .11 to .78 ppm; per cent sodium, 33 to 43; chloride, 87 to 467 ppm; sulphate, 182 to 231 ppm; nitrate, 0 to 7 ppm. The highest conductance, boron, per cent sodium, and chloride of this latter group occur in well No. 13f, indicating the possibility of its contamination from Baldwin Hills.

In the small section of the area lying between Washington and Venice Boulevards, west of Centinela Avenue, 6 wells have been sampled, including No. 23a which is just north of Venice Boulevard. Three of these are of low salinity, having: Conductance (2 only), 99.4 and 101; boron (1 only), .07 ppm; per cent sodium, 9 to 50; chloride, 58 to 77 ppm; sulphate, 179 to 218 ppm; nitrate, 0 to trace. The other 3 wells, Nos. 23a, b, and c, are of higher salinity, ranging as follows: Conductance, 117 to 249; boron (2 only), .08 to .14 ppm; per cent sodium, 23 to 25; chloride, 124 to 462 ppm; sulphate, 209 to 325 ppm; nitrate, 1 to 16 ppm. The highest concentrations of all constituents occur in Well No. 23b.

In the section lying southwest of Centinela Avenue from Washington Boulevard south to Ballona Creek, 17 wells have been sampled. Only 3 of these, Nos. 25, 25c, and 25d, are classed as of low salinity, having: Conductance (2 only), 98.2 and 98.6; boron (2 only), .10 and .11 ppm; per cent sodium (1 only), 27; chloride, 59 to 142 ppm; sulphate (1 only), 151 ppm; nitrate (1 only), 14 ppm. Ten other wells in this section are classed as of intermediate salinity, having composition ranges: Conductance, 129 to 292; boron, .13 to .58 ppm; per cent sodium, 5 to 56; chloride, 64 to 266 ppm; sulphate, 171 to 835 ppm; nitrate, 0 to 178 ppm. The highest conductance, chloride, and sulphate occur in Well No. 24c, the highest nitrate in No. 26c. Wells 26a and 26b which had 67 and 64 ppm of chloride in April, 1930, had 135 and 213 ppm of that constituent in April, 1932. Wells 26f and h are reported as having an odor of hydrogen sulphide. The 4 remaining wells in this section, Nos. 23e and 23m, 24d, and 26, are more saline. Complete analyses are available only for Nos. 23e and 26. The composition ranges are: Conductance, 283 to 359; boron, .09 to .43 ppm; per cent sodium, 23 to 35; chloride, 291 to 1058 ppm; sulphate, 460 to 674 ppm; nitrate, 0 to 133 ppm. The highest chloride occurred in No. 23m, the highest nitrate in No. 26.

In the section south of Ballona Creek, below Centinela Avenue, 9 wells have been sampled. Only one of these, No. 31, is classed as of low salinity. Its composition is: Conductance, 88; boron, .24 ppm; per cent sodium, 45; chloride, 87 ppm; sulphate, 39 ppm; nitrate, 1 ppm. Seven of the wells are of intermediate salinity with the following composition ranges: Conductance, 120 to 265; boron, .16 to 1.40 ppm; per cent sodium, 28 to 53; chloride, 106 to 373 ppm; sulphate, 17 to 437 ppm; nitrate, 0 to 6 ppm. Well No. 27a, a shallow well only 20 feet deep, located close to Ballona Creek, is highest in all constituents except sulphate and nitrate. It is probably contaminated by drainage from Baldwin Hills. No. 27b, located close by, but 150 feet deep, is the lowest of the group in conductance, chloride, and sulphate. Nos. 31a and 31b are reported to have the odor of hydrogen sulphide.

The remaining well of this group, No. 24j, is a test hole 110 feet deep, located at 5 feet elevation. It is reported that the water samples were taken successively as the hole was drilled. Only the chloride constituent was determined on the samples. The first sample, at 20 feet, contained 3980 ppm, the next at 45 feet, 220 ppm; and the 3d at 65 feet, 160 ppm. The next 2 samples from 85 and 105 feet contained 227 and 185 ppm respectively, while the last sample, from 110 feet, contained 973 ppm.

Further discussion of the wells located within three miles of the coast line occurs in Chapter XIX under the heading "Intrusion of Ocean Water." The wells and three-mile zone are delineated on Plate I, opposite page 86.

THE REDONDO-LONG BEACH AREA

This area lies west of the Inglewood Fault and south of the Venice Area. It is drained by Nigger Slough, which rises near Inglewood and empties into Los Angeles Harbor near San Pedro, following a trough between the ridge of the fault line and the palisades along the coast. Toward the southwest the ground rises in the San Pedro Hills to 1480 feet. From these hills the high ground extends northward along the coast, at elevations above 200 feet, as far as Centinela Creek at the northern boundary of the area. The divide between the drainage of Centinela Creek and of Nigger Slough near Inglewood is 100 feet above sea level.

In general a condition of overdraft exists in the area in respect to the underground waters. With a few exceptions, the static levels in the wells are below sea level. It is probable that replenishment from the delta cone of the Los Angeles River is impaired by the Inglewood Fault. The levels of underground water are 50 feet or more higher east of the fault line than west of it.

Surface Waters.

The surface waters of the area are of negligible volume except after rains. They are chiefly industrial wastes, high in chloride salinity and in boron. They are represented by 2 samples from the channel of the Los Angeles River, 4 from Nigger Slough, and 1 of oil-well water. One of the samples from the Los Angeles River was taken at Location S897, elevation 21 feet, on March 24, 1932. It is said to represent surface flow and industrial wastes. Its conductance was 3742; boron, 31.0 ppm; per cent sodium, 88; chloride, 14,289 ppm; sulphate, 16 ppm; nitrate, none. The other sample from the Los Angeles River was taken at Location S390, elevation 8 feet, on October 26, 1932, said to represent surface flow. Its composition so far as reported: Per cent sodium, 61; chloride, 332 ppm; sulphate, 291. The discharge is not reported for either sample.

The 4 samples from Nigger slough were taken in February, March, and April, 1932, from Location S824, S835, S846, and S869; elevations 10 to 15 feet. Conductance and boron were determined on the samples from the first two named locations and were: Conductance, 482 and 771; boron, 3.45 and 4.29 ppm. The ranges of composition for the other constituents for all 4 samples were: Per cent sodium, 68 to 90; chloride, 201 to 1576 ppm; sulphate, 209 to 1112 ppm; nitrate, none.

The sample said to represent oil-well waste water was from Location S1353, elevation 150 feet, taken August 30, 1932. Its composition so far as reported was: Conductance, 5330; boron, 51.2 ppm; chloride, 19,347 ppm.

Underground Waters.

In that part of the Area north of Imperial Highway 13 wells have been sampled. Only one of these has a chloride content above 142 ppm and that is a shallow well, No. 35. This well and one other, No. 36a, have conductances above 100. The boron content is below the critical concentration in all the samples tested for this constituent, and only 1 well, No. 28, shows high nitrate content, 27 ppm.

Between Imperial Highway and Rosecrans Boulevard 15 wells have been sampled, including those in El Segundo. In none of these is the conductance above 100 or the chloride content more than 142 ppm. Boron and nitrates are low in all samples tested for these constituents.

In the Area south of Rosecrans Boulevard and west of Western Avenue, including the beach towns south of El Segundo, 29 wells have been sampled. Of these only 3 have conductances above 100 and they are located along the edge of the San Pedro Hills, Nos. 95, 130, and 130a. No sample contained more than 142 ppm of chloride. Again the boron and nitrate are low and the sulphates are very low in many of the deeper wells.

South of Dominguez Hill to Carson Street and east of Western Avenue are 13 wells, mostly on low ground adjacent to Nigger Slough. Three of these, Nos. 107c and 107d, and 114, are shallow wells, less than 50 feet deep, the water of which is saline like that from the Slough at S824 and S835. The water from the deeper wells in this section is of low salinity.

South of Carson Street, between Main Street and Narbonne Avenue 16 wells have been sampled. Of these, 5 have conductances above 100 with more than 142 ppm of chloride. One of these more saline wells, No. 133n, is only 105 feet deep, while the most saline of the 10 good wells is 90 feet deep. The other 4 saline wells, Nos. 133f, 133k, 133d, and 133b, are the most southerly of the wells sampled. Two of them are located near Bixby Slough and two are on low ground near the tidal basin north of San Pedro. Nos. 133f and 133k are located at elevations of 30 and 25 feet. Both have been sampled repeatedly. The first named is much the more saline of the two but the boron content of both is high. Their composition ranges are: Conductance, 218 to 605; boron, 1.30 to 1.86 ppm; per cent sodium, 71 to 91; chloride, 419 to 1740 ppm; sulphate, 0 to 17 ppm; nitrate, none. The character of this salinity with its high boron content and high ratio of chloride to sulphate suggest contamination from oil-well waters.

East of Main Street and south of Carson Street there are 49 wells. Of these, 21 have conductances less than 100 and chloride contents less than 142 ppm; the other 28 range in salinity up to that of sea water, No. 137c. Of these 29 more saline wells, 10 have conductance below 300 or chlorides below 355 ppm and thus might be used for irrigation under certain conditions with some hazard. The waters of the remaining 18 wells are regarded as too saline for agricultural use.

It is not clear that the high salinity of all these 18 wells is due to the invasion of sea water. That may be the cause in respect to those located adjacent to or south of Anaheim Street. But there is also a group of wells of high salinity farther north on the west side of the channel of the Los Angeles River in the vicinity of Wardlow Road. It seems probable that the salinity of this northern group is not due to sea water invasion but rather that it comes from industrial wastes originating in the neighborhood, possibly from Signal Hill.

The Redondo-Long Beach Area includes the major portion of the ocean frontage of the South Coastal Basin, extending as it does from the outlet of Ballona Creek to that of the San Gabriel River. From the evidence here available there is no clear indication of sea-water invasion along the western front, north of the San Pedro Hills. Along the southern front from San Pedro to the mouth of the San Gabriel River there are a number of wells in which the water is saline and in a few of them very close to the sea-water channels, back from the beach, the salinity is due to sea-water invasion. In respect to the majority of the more saline wells farther from the beach, the composition of the salts is such as to support the view that the salinity is due chiefly to contamination by oil-well waters.

In respect to the deeper wells in the southern part of the area it should be remarked that the waters are usually very low in sulphate. This is the most noticeable in the wells south of the line of Carson Street. This is illustrated by wells 88 and 94, to the west, and by Nos. 115, 134b, and 135e, in all of which sulphate is reported as absent or present only as a trace. The last named is only 100 feet deep with a high chloride content, yet the absence of sulphates indicate that the salinity is not due to sea-water invasion. The same is true in respect to Nos. 133f and 133k in which conditions are in marked contrast with those found in Nos. 133d and 133b. In the last two the high sulphate content (161 and 119 ppm) suggests the probability of sea-water contamination. It is to be noted also that the low sulphate content here mentioned is usually associated with a high per cent sodium. From this it is to be inferred that the processes involved in breaking down the sulphates probably originally contained in these waters, also caused the precipitation of most of the calcium and magnesium normally to be found in such waters.

Further discussion of the wells located within three miles of the Coast line occurs in Chapter XIX under the heading "Intrusion of Ocean Water." The wells and three-mile zone are delineated on Plate I, opposite page 86.

CHAPTER XIV

THE LOWER SAN GABRIEL AREA

The Lower San Gabriel Area as here circumscribed includes that part of the coastal plain south of Whittier Narrows that lies between the Rio Hondo and Coyote Creek. It extends south, not to the coast, but to the Inglewood Fault that passes in a southeasterly direction through Signal Hill across the San Gabriel just above its mouth. The Coyote Hills are not in this Area but it includes the drainage at the head of Coyote Creek west of Brea Canyon.

Surface Waters.

The quality and volume of the water passing as surface flow through the Whittier Narrows into this Area is shown in tables 7 and 12. The surface waters within the Area are represented by 1 sample from the San Gabriel River, samples from 3 locations on Coyote Creek, 2 samples from open drains and 1 sample of oil-well waste water. The sample from the San Gabriel River, Location S502, elevation 5 feet, was taken on March 2, 1932. Conductance, 300; boron, 1.80 ppm; per cent sodium, 72; chloride 586 ppm; sulphate, 288 ppm; nitrate, none; discharge not reported.

The 3 locations on Coyote Creek are: S1062, elevation 50 feet; S1054, elevation 40 feet; and S1028, elevation 20 feet. The sample from the first named location, taken March 24, 1932, had: Conductance, 92.1; boron, .44 ppm; per cent sodium, 50; chloride, 94 ppm; sulphate, 64 ppm; nitrate, 10 ppm; discharge, 0.15 cfs. At Location S1054, 3 samples were taken in February and March, 1932, and one on January 31, 1933. No discharge is reported for the first 3 samples, their composition ranges: Conductance, 281 to 297; boron, 2.24 to 2.43 ppm; per cent sodium, 73 to 75; chloride, 674 to 737 ppm; sulphate, 82 to 83 ppm; nitrate, 20 to 23 ppm. The sample taken in January, 1933, represents a discharge of approximately 30 cfs and its salinity is low. Conductance, 59.2; boron, .30 ppm; per cent sodium, 46; chloride, 48 ppm; sulphate, 82 ppm; nitrate, 13 ppm. The sample from Location S1028, taken March 2, 1932, had only a partial analysis: Conductance, 370; boron, 2.34 ppm; chloride 843 ppm.

One of the open-ditch samples is from Location S1061, elevation 66 feet, taken February 12, 1932. Conductance, 95.9; boron, .34 ppm; chloride, 106 ppm; the other constituents not determined. The other sample is from Location S959, elevation 25 feet, discharge 1.0 cfs, taken August 20, 1931. Its composition: Conductance, 37.8; boron, not determined; per cent sodium, 69; chloride, 20 ppm; sulphate, 2 ppm; nitrate, trace. The composition of this sample indicates that it represents an artesian flow or outbreak of water from deeper strata and not true surface water.

The sample of oil-well waste water is from Location W1636, at 155 feet elevation, taken September 5, 1932. Conductance, 942; boron, 9.40 ppm; per cent sodium, 94; chloride, 2929 ppm; sulphate 32 ppm; nitrate none.

Subsoil Waters.

In the Lower San Gabriel as in the Lower Santa Ana Area there are certain sections in which the subsoil is saturated with water. This water has been sampled at 11 points in the Area. At 4 of these, Nos. 877n, 886g, 902m, and 916i, it was found to have low salinity. The composition ranges for these 4 are: Conductance, 46.3 to 98.5; boron, .15 to .17 ppm; per cent sodium, 19 to 45; chloride, 13 to 41 ppm; sulphate, 23 to 61 ppm; nitrate none. The samples from 6 locations were of intermediate salinity, with composition ranges: Conductance, 122 to 440; boron, .33 to 1.44 ppm; per cent sodium, 24 to 90; chloride, 46 to 967; sulphate, 78 to 473; nitrate, none. The samples from Locations 901k and 916h, were low in chloride and sulphate but high in bicarbonate. The remaining sample of the subsoil group, Location 897f, was very saline: Conductance, 3310; boron, .45 ppm; per cent sodium, 61; chloride, 11,981 ppm; sulphate, 3991 ppm; nitrate none.

Underground Waters.

In the section of the Area between Rio Hondo and Los Angeles River on the west and the San Gabriel on the east, extending from the northern boundary of the Area in Whittier Narrows to the southern boundary at the Inglewood Fault, 62 wells have been sampled. It does not appear that any useful purpose would be served by subdividing this section for descriptive purposes. The waters drawn upon by all the wells sampled that penetrate below the subsoil, are of low salinity, the highest concentrations reported being from the wells north of Redondo Boulevard. In this Area as in the Lower Santa Ana Area some of the wells of lowest salinity are found near the coast. The concentration ranges for these 62 wells are: Conductance, 31.9 to 77.9; boron (7 only), .12 to .21 ppm; per cent sodium, 15 to 89; chloride, 5 to 36 ppm; sulphate, 0 to 129 ppm; nitrate, 0 to 9 ppm. The highest per cent sodium and the lowest sulphates occur in the wells near the coast thus showing an analogy with conditions reported for the Redondo-Long Beach Area.

In the section east of the San Gabriel River, north of Telegraph Road and of Coyote Hills in the vicinity of La Habra, 21 wells have been sampled. These are located in a region close to Puente Hills and their waters are characterized by a higher sulphate content. Only 3 of the wells in this section are classed as of low salinity, Nos. 819x, 941d, and 970m, with the following composition ranges: Conductance, 45.3 to 99; boron (1 only), .33 ppm; per cent sodium (1 only), 44; chloride, 14 to 84 ppm; sulphate (1 only), 131 ppm; nitrate (1 only), 2 ppm. No. 970m is the only one having a complete analysis. The other 18 wells in this section are classed as of intermediate salinity, having the following ranges: Conductance, 107 to 327; boron, .16 to .55 ppm; per cent sodium (10 only), 25 to 61; chloride, 50 to 318 ppm; sulphate (10 only), 131 to 423 ppm; nitrate (10 only), 0 to 22 ppm.

In the section east of the San Gabriel River, between Telegraph Road and Rosecrans Boulevard, including Santa Fe Springs, 27 wells have been sampled, some of them several times. Of this group 15 are classed as low salinity and of these all but 3 are located east of Norwalk Boulevard. The composition ranges for the 15 are: Conductance, 39.2 to 92.1; boron (8 only), .09 to .43 ppm; chloride, 9 to 130 ppm;

sulphate (11 only), 0 to 106 ppm; nitrate (9 only), 0 to 7 ppm. The composition ranges for the remaining 12 are: Conductance, 117 to 335; boron (7 only), .12 to 1.73 ppm; per cent sodium (8 only), 17 to 54; chloride, 84 to 870 ppm; sulphate (8 only), 48 to 210 ppm; nitrate (7 only), 0 to 4 ppm. Two of these wells are notably high in boron, No. 824y, 1.25 ppm, and No. 852m, 1.73 ppm. Both of these are high in conductance and chloride also.

In the section south of Rosecrans Boulevard, between San Gabriel River and Coyote Creek, 14 wells have been sampled. Unlike the wells to the north, these are all of low salinity, thus resembling those west of San Gabriel River. Their concentration ranges are: Conductance, 42.1 to 60.5; boron (3 only), .10 to .12 ppm; per cent sodium, 22 to 79; chloride, 7 to 34 ppm; sulphate, 19 to 88 ppm; nitrate none.

In respect to the Area as a whole it may be said that except for the section in the vicinity of Santa Fe Springs and north of Coyote Hills near the Puente Hills the underground waters are of low salinity. Those north of Coyote Hills are rather high in sulphate but generally low in per cent sodium. In the vicinity of Santa Fe Springs there is evidence of boron and chloride contamination both in wells and in surface waters.

CHAPTER XV

THE LOWER SANTA ANA RIVER AREA

This Area includes the segment of the Coastal Plain between Coyote Creek on the west and the channel of the Santa Ana River on the east. Above the edge of the Coastal Plain it includes the southwesterly drainage of the Puente Hills from Rodeo Canyon to the Santa Ana Canyon, both inclusive. Two zones of faulting cross the Area in the northwest-southeast direction. One, the Whittier Fault, lies near the base of the Puente Hills and the other, the Inglewood Fault, coincides approximately with the beach line.

The irrigation supplies for the area are replenished, in addition to local rainfall, chiefly from the Santa Ana River. This stream brought into the canyon above the area during the year ending September 30, 1932, a total of 83,000 acre-feet of water as measured by the United State Geological Survey at the gaging station near the Orange County line. During the irrigation season the major part of this discharge is diverted from the stream by two canals, one of which, that of the Anaheim Union Water Co., serves land within this area.

Surface and Subsoil Waters.

The quality of the irrigation water diverted from the Santa Ana River is shown in table 12. Its conductance ranges from 73 to 87 and its chloride content from 69 to 101 ppm. The water contributed to the irrigated lands of the Area from the Puente Hills is ordinarily of small volume. Its quality is indicated by samples from the creeks in Rodeo, Soquel, and Carbon Canyons, (Locations S1835, S1897, and S1897A). The conductances of these samples range from 224 to 979, the chloride contents from 195 to 1411 ppm, and the boron from .50 to 7.23 ppm. Two springs in Carbon Canyon, Locations S1925 and 1096k, with conductances of 583 and 667 and boron contents of 1.38 and 5.14 ppm indicate that the soils and soft rocks of the Puente Hills may contain a good deal of soluble material.

Prior to the present agricultural development in this Area with its accompanying draft on the underground water by numerous irrigation wells the underground water was under such pressure that some of the earlier wells in the lower part of the Area were artesian. It seems probable that the sediments of the Coastal Plain were deposited in strata of which some are composed of finer material such as silt or of cemented material through which water moves slowly if at all. Some of the permeable strata are probably connected with and replenished by water from the Santa Ana River as it emerges from its lower canyon east of Anaheim, 200 feet or more above sea level. The hydrostatic pressure resulting from replenishment at this source and confinement under the impermeable strata probably accounts for the artesian wells of the lower part of the Area.

It is evident that these impermeable strata in the sediment are not without breaks or leaks because there are several places in the lower part of the Area where springs occur, sometimes in abundance to form swampy areas. One such spring, Location S599B, yields water of such

low salinity (conductance 44.5) as to indicate that it is derived from some stratum that is connected with such fresh water as would be carried by the Santa Ana River in flood. The composition of the water from this spring is very similar to that from a neighboring well, No. 998h, which is 282 feet deep. The condition of hydrostatic pressure in the deeper permeable strata of the Coastal Plain sediments implies the existence not only of overlying impermeable strata but also of some barrier that impedes the escape of the deeper underground water to the Sea. It seems probable that such a barrier exists along the line of the zone of fracture of the Inglewood Fault.

The impermeable strata referred to above may account for the fact that in certain parts of the Area water accumulates in the subsoil to the detriment of crop plants. This has necessitated the construction of drainage systems of which there are several in this Area. The present investigation has included sampling the water of these drainage systems at a number of points. In general this subsoil water as sampled from the drains and from shallow test holes is more saline than that from the deeper strata, obtained through irrigation wells. Among the 42 samples of drainage and subsoil water the range of salinity as expressed by conductance and chloride content is from 53.3 and 30 respectively up to the concentration of sea water, found in some of the sloughs near the beach. Where the low concentrations are found it seems probable that the drains are drawing off water that is rising as springs from the deeper permeable strata by way of natural leaks through the overlying, less permeable, strata.

Underground Waters.

The deeper water of the Area, as obtained by wells, is in general of such low salinity as to be safe for irrigation use. In the upper part of the Area, north of Orangethorpe Avenue and east of Placentia, 38 wells have been sampled, excluding No. 1096k referred to above, and Nos. 1096L and 1097c, which will be referred to later. The conductance has been determined on 24 of these samples and ranges from 56.6 to 153. The chloride has been determined for all of them; it ranges from 27 to 271 ppm. The boron content, where this constituent has been determined, does not exceed .58 ppm. The two wells, Nos. 1096L and 1097c, require special comment. The first is an abandoned well located in Brea Canyon where its high salinity may be due to industrial contamination. The other is a well of unknown depth, located near Carbon Canyon Creek. Its water has a conductance of 606, a boron content of 5.6 ppm and a chloride content of 405 ppm. This composition is similar to that of the waters of Carbon Creek and Soquel Canyon Creek as sampled at Locations 1897 and 1897A and the water is clearly not safe for irrigation use.

In the segment of the area between Orangethorpe and Katella Avenues which includes Anaheim, 24 wells have been sampled. Of these the conductance has been determined on 15. It ranges from 45 to 93, indicating rather less salinity in this part of the Area than north of it. The chloride content for all 24 samples ranges from 14 to 83 ppm, confirming the indications of the conductance. Only 2 boron determinations have been made and the highest of these is .19 ppm.

In the next segment of the Area, between Katella and Ocean Avenues, 17 wells have been sampled. The conductance has been determined on 10 of them and it ranges from 37.9 to 82. The chlorides, determined for all samples, range from 14 to 77 ppm, while the boron, reported on 4 samples, does not exceed .12 ppm. In this portion of the Area also the salinity of the water is low.

In the portion of the Area south of Ocean Avenue and west of Bolsa Chica Street, which includes the delta of Anaheim Creek, samples have been obtained from 12 wells of which 3 are reported as artesian. Conductances are available from 6 of them and range from 31 to 45.4. The chlorides as reported for all 12 range from 14 to 29 ppm. These results indicate that the water from the deeper strata, even close to the ocean front but behind the Inglewood Fault, is not contaminated with sea water.

The next segment of the Area, lying between Bolsa Chica Street and Huntington Beach Boulevard, south of Ocean Avenue, includes the Wintersburg Area (Inset 4 on the map). Twenty-four wells have been sampled in this part of the Area of which one, No. 997v, will be discussed later. Conductances have been determined on 14 of the 23 samples. These range from 34.3 to 68.9. The chlorides for all 23 samples range from 13 to 85 ppm. Eight boron determinations range below .28 ppm. All these waters are of such low salinity as to indicate the absence of contamination either from the ocean or from the overlying subsoil waters as sampled from the drains. The sample from Well No. 997v is very different in composition from the others in this section. Its conductance is 537, its boron content 3.22, and its chloride content 1757 ppm. The sulphate content is low, 14 ppm, which, taken with the high boron content, suggests that the salinity here found may be due to contamination by oil-well water rather than from ocean water.

The section between Huntington Beach Boulevard and Verano Street, south of Ocean Avenue, includes that portion of the delta of the Santa Ana River between Huntington Beach on Los Bolsas hill and Costa Mesa, (Inset 5 on the map). In this section samples have been obtained from 65 wells. In respect to conductance which was determined for 42 of the wells, the range is from 37.3 to 275. Only 9 of the 42 have conductance of more than 100. In chloride content the 65 wells range from 12 to 18,236 ppm. Only 15 of the 65 contain chlorides in excess of 150 ppm. Boron has been determined for 33 of the 65 wells and its concentration ranges up to 1.29 ppm; only 7 of the 33 contained boron in excess of .5 ppm. From these data it is to be inferred that the water from some 50 of the 65 wells in this area would be entirely safe for irrigation use. Of the 15 wells classed as having water of doubtful quality or too saline for irrigation use, only 2 show evidence of sea water contamination; these are Nos. 1274 and 1274b, both of which are very close to the beach. While only partial analyses are available of samples from the standing water, in these two wells, the high chloride concentration and their proximity to the beach indicate marine contamination. Six of the others are located in or adjacent to Huntington Beach and the composition of the salts indicates contamination from oil-well waters. Five others are located near the base of Costa Mesa and their composition indicates by its high boron content, contamination from the fault zone. Well 1261b has been sampled at 10

different times during the years 1930 to 1932. In the summer of 1931 the samples showed increasing chloride content, from 16 ppm in March of that year to 542 ppm in October. A similar increase in salinity is reported from Well 1262a.

In the section of the area west of Verano Street and south of Ocean Avenue, 12 wells have been sampled. Of these only 8 are deep, 4 being so shallow (20 feet or less) that their samples may be taken to represent subsoil water. For the 8 samples from the deeper wells the conductances range from 45.5 to 85.7, the chlorides from 18 to 57 ppm; so that the waters are all safe for irrigation use. The samples from the 4 shallow wells are more saline, ranging in conductance from 116 to 210. The boron in the deep-well samples ranges below .21 ppm, while in the samples from the shallow wells it ranges up to .89 ppm.

A review of the conditions described above brings out the fact that the irrigation waters now being drawn from the deeper strata in the sediments of the Coastal Plain are definitely less saline than the water of the Santa Ana River as sampled at Prado. It is here assumed that these deeper strata are, or have been in the past, replenished from the Santa Ana River. How then is the lower salinity of their waters to be accounted for? It seems probable that the deeper strata are, or have been charged mainly with water when the Santa Ana is in flood and when the water it carries is much lower in salinity than the normal flow as sampled at Orange County line, of which a large part is seepage from the irrigated lands that drain to the river above the Lower Canyon.

Further discussion of the wells located within three miles of the coast line occurs in Chapter XIX under the heading "Intrusion of Ocean Water."

CHAPTER XVI

THE SANTA ANA-IRVINE AREA

The Santa Ana-Irvine Area lies southwest of the Santa Ana Mountains and southeast of the Santa Ana River. The contiguous watershed of the Santa Ana Mountains discharges in part through a number of small creeks into the southeastern part of the Area, but most of it discharges by way of Santiago Creek, the channel of which crosses the northern part of the Area to join the Santa Ana River. The local rainfall and run-off is supplemented by water diverted from the Santa Ana River, in the Lower Canyon, through the canal of the Santa Ana Valley Irrigation Company and by water from Santiago Creek.

Surface and Subsoil Waters.

The quality of the water diverted from the Santa Ana River is discussed in an earlier paragraph and is shown also in Table 12. The volume of discharge from the mountains by way of Santiago Creek is reported by the United States Geological Survey as 2080 acre-feet for the year ending September 30, 1931, and as 12,700 acre-feet for the year ending on the same day in 1932. Of the volume reported as discharge for 1932, 6550 acre-feet was held in storage in Santiago Reservoir which was dry at the beginning of the season. During 1932, 5 samples of this discharge were taken, one each month from February to June. The ranges in composition were as follows: Conductance, 61.1 to 93.4; boron, .05 to .16 ppm; per cent sodium, 16 to 26; chloride, 0 to 34 ppm; sulphate, 163 to 329 ppm; nitrate, trace to 2 ppm. It is evident from these analyses that the drainage from the Santa Ana Mountains to the westward, like that to the northward into the Temescal Area, is largely of sulphate waters with a low percentage of sodium.

The subsoil waters of the Area have been sampled at 13 points from tile drains or open drainage ditches. Eight of these locations were at manholes of the tile lines of the Newport Drainage District, and the samples were taken on February 3, 1932, except one sample that was taken two weeks earlier. The quality of the subsoil water collected by this drainage system may be shown best by stating the conductances of the samples in the order of their locations on the lines from the north, in the direction of the outlet. At Location S14508, conductance, 148; at S14509, 248; at S13300, 248. From the east and south: Location S13301, conductance, 61.3; S13291, 232; S13281, 259; at the outlet S13260A, the conductance on February 3 was 259, while at the same location on January 19 it was 347. Complete analyses were reported for the two samples taken at the outlet of the system on January 19 and February 3, 1932. The composition of these follows: Conductance, 347 and 259; boron, .46 and .33 ppm; per cent sodium, 57 and 54; chloride, 250 and 167 ppm; sulphate, 1323 and 957 ppm; nitrate, 18 and 10 ppm. A sample from an open ditch of the Newport system taken at Location S13262 in June, 1932, is reported as containing 263 ppm chloride.

Samples were taken from two locations on the system of the Delhi Drainage District. At Location S13313, one sample was taken April

1, 1931, and found to contain 306 ppm chloride; another taken at the same place on June 1, 1932, contained 1302 ppm. A sample taken from another open ditch of the same system at Location S13314, in June, 1930, contained 425 ppm chloride; 1976 ppm sulphate, and had a sodium percentage of 73.

The drainage ditches of The Irvine Company were sampled at two locations. At S13362, samples were taken on April 1, and June 1, 1932, and found to contain 641 and 481 ppm of chloride respectively. At S13352 a sample taken April 1, 1932, contained 1006 ppm chloride. A sample of subsoil water obtained from a test hole, No. 1180a, in December, 1930, contained 4319 ppm chloride. From such evidence as is available it is to be inferred that the subsoil water of this Area, like that of the drainage from the Santa Ana Mountains, has a higher concentration of sulphate than of chloride.

Underground Waters.

In respect to the quality of the underground waters, the first section of the Area to be considered is the one including the delta of Santiago Creek and the city of Orange. It is bounded on the south by 17th Street and includes 17 wells that have been sampled. Conductances are reported for only 6 of these and boron for only two, Nos. 1058a and 1109. The wells of the section fall into 2 groups with respect to the relative concentrations of chloride and sulphate. One group includes 3 wells in which the chloride concentration is approximately equal to that of the sulphate, Nos. 1058a, 1106a, and 1151a. These wells are all located close to the channel of the Santa Ana River and may be assumed to represent the characteristics of that stream. Their composition ranges are: Conductance, 55.5 to 62.6; boron (1 only), .09 ppm; per cent sodium, 26 to 33; chloride, 30 to 46 ppm; sulphate, 30 to 62 ppm; nitrate, 4 to 7 ppm. In the other group of 14 wells the composition ranges are: Conductance (3 only), 21 to 61.9; boron (1 only), .21 ppm; per cent sodium, 13 to 59; chloride, 20 to 67 ppm; sulphate, 58 to 275 ppm; nitrate, 0 to 14 ppm. Taken as a whole, the waters of this section appear to be of low salinity.

In the section lying between Newport Boulevard and Culver Road, southwest of the main line of The A. T. and S. F. Railway, 20 wells have been sampled. Conductances have been reported for only 3 of these and boron contents for only two. The situation in this section in respect to the quality of the underground waters appears to be more complicated than in the two sections previously discussed. In a few of the wells the salinity as measured by the chloride content is intermediate to high, while in several other wells the data available indicate that the salinity is low. Nine of the wells classed as of low salinity show the following composition ranges: Conductance (1 only, No. 1244a), 64.8; boron contents not reported; per cent sodium, 18 to 92; chloride, 13 to 92 ppm; sulphate, 3 to 150 ppm; nitrate, 0 to 8 ppm. Two of the wells of this group have such high sodium percentages that their waters might be classed as of doubtful quality for irrigation, notwithstanding their low salinity. These are Nos. 1243a and 1244a, both located on low ground north of the slough tributary to Newport Bay. Of the 11 other wells in this section, 8 may be classed as of intermediate salinity with the following composition ranges: Conductance (1 only), 101.3; boron not reported; per cent sodium, 20 to 94; chlo-

ride, 36 to 195 ppm; sulphate, 1 to 165 ppm; nitrate, 0 to 3 ppm. In this group are 4 wells with high sodium percentages; No. 1227m, which is 1026 feet deep, with per cent sodium, 70; No. 1243e, 720 feet deep and Nos. 1244d and 1244i, depth not reported, with sodium percentages, 94, 92, and 77, respectively; these 3 are located on the low ground north of Newport Bay Slough.

The 3 remaining wells in this section that call for special consideration are Nos. 1228e, 1227h, and 1231g. The first named is 592 feet deep and has per cent sodium, 64; chloride, 460 ppm; sulphate, 715 ppm. No. 1227h is 808 feet deep. Eight samples from it have been analyzed since 1920 and show the following composition ranges: Conductance, 88.1 to 96.5; boron, .67 to 1.00 ppm; per cent sodium, 88 to 98; chloride, 163 to 186 ppm; sulphate, 0 to 160 ppm; nitrate, 0. No. 1231g is 1346 feet deep and analyses are reported on 8 samples taken since 1923 with the following composition ranges: Conductance (3 only), 62.6 to 65.5; boron (3 only), .38 to .47 ppm; per cent sodium, 39 to 100; chloride, 83 to 1085 ppm; sulphate, trace to 152 ppm; nitrate not reported. In explanation of the wide ranges in composition for the last 2 wells it should be said that they have been interconnected to an irrigation pipe line and some of the samples may not be truly representative of the wells, and also the sample from No. 1231g, having the sodium percentage of 39, was taken after the casing had been plugged to cut off water from some of the lower strata.

In the section between Newport Boulevard and Culver Road, but northeast of the main line of The A. T. and S. F. Railway, 35 wells have been sampled. Conductance and boron determinations have been reported for only 6 of these, consequently the salinity of the others must be judged by their concentrations of chloride and sulphate. Twenty-two of these 35 wells are judged, from the analytical data available, to be of such low salinity as to be safe for irrigation use. The composition ranges for this group are: Conductance (1 only), 94.5; boron (1 only), .20 ppm; per cent sodium, 15 to 63; chloride, 23 to 116 ppm; sulphate, 46 to 261 ppm; nitrate, 0 to 17 ppm. The next group, regarded as of intermediate salinity and possibly of doubtful safety for irrigation, includes 10 wells having the following composition ranges: Conductance (5 only), 110.1 to 172; boron (5 only), trace to .65 ppm; per cent sodium, 19 to 68; chloride, 75 to 259 ppm; sulphate, 33 to 700 ppm; nitrate, 0 to 28 ppm. The 3 wells that are regarded as probably too saline for safe irrigation use are Nos. 1207n, 1211e and 1211r. Their composition ranges are: Conductance not reported; boron not reported; per cent sodium, 39 to 78; chloride, 361 to 625 ppm; sulphate, 152 to 1222 ppm; nitrate, 0 to 44 ppm. The following 6 wells are reported as having sodium percentages above 60: Nos. 1207e, 1210f, 1211i, 1211q, 1211r, and 1212d. Of these, 3 range in depths from 1206 to 1412 feet, one is 870 feet, and the other two are 236 and 271 feet.

In the section between Culver Road and Central Avenue, northeast of United States Highway 101, 10 wells have been sampled but conductance and boron have been determined for only two. Judged from the data as to chloride and sulphate, 2 of the wells are classed as of low salinity, with the following composition ranges: Conductance not determined; boron not determined; per cent sodium, 30 to 68; chloride, 54 to 96 ppm; sulphate, 105 to 150 ppm; nitrate, none.

The other 8 wells, classed as of doubtful quality, have the following composition ranges: Conductance (2 only), 176 to 295; boron (2 only), .28 to .99 ppm; per cent sodium, 36 to 61; chloride, 54 to 596 ppm; sulphate, 100 to 700 ppm; nitrate, 0 or not determined.

Between Culver Road and Central Avenue, southwest of United States Highway 101, 18 wells have been sampled. Conductance and boron determinations are reported for 5 of them. With the analytical data available, 10 of these wells are classed as of low salinity and have the following composition ranges: Conductance (2 only), 104 to 113; boron (2 only), .10 to .20 ppm; per cent sodium, 26 to 64; chloride, 39 to 165 ppm; sulphate, 22 to 168 ppm; nitrate, 0 to 17 ppm. The other 8 wells of higher salinity have the following composition ranges: Conductance (3 only), 95.7 to 160; boron (3 only), .10 to 1.02 ppm; per cent sodium, 35 to 96; chloride, 100 to 616 ppm; sulphate, 3 to 722 ppm; nitrate, 0 to 28 ppm. Two of these wells are regarded, on the basis of their analyses, as unsuited for irrigation use; No. 1222k, because of its high salinity and No. 1225e because of its high sodium percentage and high boron content.

In the section southeast of Central Avenue 24 wells have been sampled, including 6 that are located beyond the boundary of the watershed; conductance and boron determinations are reported for 4 of them. On the basis of the available data, 14 of these wells are classed as of low salinity and probably safe for irrigation use. Following are the composition ranges: Conductance (3 only), 90.5 to 97.2; boron (3 only), .18 to .20 ppm; per cent sodium, 20 to 62; chloride, 30 to 128 ppm; sulphate, 75 to 320 ppm; nitrate not reported. The 10 wells of higher salinity have the following composition ranges: Conductance (1 only), 122; boron (1 only), .20 ppm; per cent sodium, 30 to 85; chloride, 54 to 923 ppm; sulphate, 92 to 1052 ppm; nitrate (1 only), 2 analyses, 0 to 4 ppm. Three of the wells of this latter group, Nos. 1218, 1219b and 1219d are regarded as too saline for safe irrigation use.

For the major portion of this area, and particularly in respect to the southeastern part of it, the available data appear to be inadequate for a clear understanding of the conditions influencing the quality of the underground water.

CHAPTER XVII

SEWAGE EFFLUENTS AND INDUSTRIAL WASTE WATERS

It is not pertinent here to discuss in technical detail the subject of sewage disposal. Only the general regional and agricultural implications of the situation in the South Coastal Basin can be considered. The analytical data available are not adequate to warrant detailed consideration or satisfactory estimates in respect to the agricultural aspects of the problem. Such data as are available indicate that the concentration and composition of the dissolved salts in sewage effluents are different not only from season to season throughout the year but from hour to hour throughout the day. Because of this fact it does not seem advisable to give much weight to estimates based on the analyses of the few and occasional samples now available. The estimates in respect to the volume of sewage effluent appear to have more validity.

The sewage disposal plants in the South Coastal Basin may be grouped into two classes: (1) Those discharging into the Ocean; and (2) those discharging within the Basin. It is estimated that those of group 1 discharge annually 166,000 acre-feet of water, while those of group 2 discharge 27,000 acre-feet. Much of the discharge of the latter group is used either directly or indirectly for irrigation within the Basin.

Of the sewage disposal plants that discharge into the Ocean, analytical data are available from three: The Los Angeles County Sanitation District, which serves several cities and industrial plants in the southeastern part of Los Angeles County, discharging annually some 15,000 acre-feet of water; the Hyperion plant, serving the city of Los Angeles, and discharges annually some 123,000 acre-feet of water; and the Orange County Cities Joint Disposal System, which serves several of the cities of Orange County and discharges 5000 acre-feet of water annually. In respect to the first named, analyses are available for 26 samples taken occasionally from July, 1930, to December, 1932. The composition ranges are: Conductance, 133 to 203; boron, .46 to 1.03 ppm; per cent sodium, 55 to 80; chloride, 135 to 202 ppm; sulphate, 85 to 240 ppm; nitrate (3 only), 0 to 1 ppm. Analysis of the chloride content of waters (information from Mr. W. T. Knowlton) discharged by the Hyperion plant from November 23, at 8 a.m. to November 29, 1927, at 6 a.m., sampled at two hour intervals, show chloride varying from 106 to 340 ppm with an average content of 170 ppm. For the Orange County plant the only data available are based on 8 samples taken consecutively on December 27 to 30, 1932. The composition ranges are: Conductance, 261 to 570; boron, 1.88 to 5.74 ppm; per cent sodium (3 only), 74 to 86; chloride, 517 to 1448 ppm; sulphate (3 only), .49 to .56 ppm; nitrate (3 only), none. It is assumed that the high salinity of these samples is due largely to the fact that this sewage outfall carries the discharge collected by the Waste Water Disposal Company from certain oil fields in the northern part of Orange County, the composition of which is discussed in a subsequent paragraph.

For the group of sewage disposal plants discharging within the Basin, analytical data are available from 8 of them. The data for 3 of these 8 are meagre. For the city of Corona 2 samples, taken on December 30, 1932; for the city of Riverside one sample, taken on February 3, 1933; and for the city of Redlands 2 samples, taken on February 1 and 3, 1933. It should be noted in respect to the samples from these interior cities that citrus fruit packing houses sometimes use boron compounds in the water used for washing the fruit and these wash waters may find their way into the sewer systems. The aggregate annual discharge of sewage from these 3 cities is estimated as 4000 acre-feet. The composition ranges for the 5 samples are: Conductance, 88.2 to 128; boron, .80 to 10.64 ppm; per cent sodium, 21 to 59; chloride, 302 to 543 ppm; sulphate, 20 to 95 ppm; nitrate, 0 to 18 ppm.

The data for 4 other plants of this interior group are somewhat more numerous. The cities represented are: (1) Pasadena, with 10,000 acre-feet discharge annually; (2) Whittier, with 1000 acre-feet; (3) Pomona, with 1000 acre-feet; and (4) San Bernardino, with 4500, a total of 16,500 acre-feet. These discharges are represented by 12 samples from Pasadena, 9 from Whittier, 16 from Pomona, and 10 from San Bernardino, taken at various times from 1929 to 1933. The composition ranges for these 47 samples are: Conductance, 58.7 to 118; boron, .09 to 2.84 ppm; per cent sodium, 35 to 67; chloride, 39 to 146 ppm; sulphate, 15 to 72 ppm; nitrate (14 only), 0 to 210 ppm.

The remaining plant of the interior group is the Experimental plant of the city of Los Angeles at Griffith Park. This plant has a capacity of 224 acre-feet annually. The following composition of its discharge is reported by Mr. R. F. Goudey as the mean of some 25,000 analyses: Chloride, 85 ppm; sulphate, 125 ppm; nitrate, 3 ppm; calcium (10 only), 86 ppm; magnesium (10 only), 30 ppm.

The available data in respect to industrial waste waters originating in the Basin is even more fragmentary than that of the sewage effluents. No discharge data are reported to indicate the significance of the analytical results and of the 44 analyses assembled only 25 are to be classed as complete in that the per cent sodium may be computed from the data, and boron determinations are reported for only 9 samples. The samples reported may be grouped as follows: (1) Those discharged into Nigger Slough in the Redondo-Long Beach Area; (2) those discharged into the Los Angeles River and Rio Hondo; (3) discharged in the Ocean through the Orange County Cities Joint Outfall; and (4) disposition not definitely known but presumably discharged within the Basin.

In group 1, Nigger Slough, 4 sampling locations are represented by 6 samples, all taken in 1932. Their composition ranges so far as reported are: Per cent sodium, 66 to 90; chloride, 29 to 13,440 ppm. The highest chloride occurs at W835. In group 2, Los Angeles River and Rio Hondo, there are 10 sampling locations represented by 19 samples, all taken in 1932. Their composition ranges are: Per cent sodium, 30 to 94; chloride, 0 to 850 ppm; sulphate, 3 to 12,315 ppm. The highest sulphate concentrations occur at Locations W2789 and W2799. The analyses of group 3, 8 in number, are all from the outlet sump of the Waste Water Disposal Company, Location W15604, taken

from June, 1927, to December, 1932. The composition ranges are: Per cent sodium (2 only), 98 and 99; chloride, 4841 to 6310 ppm; sulphate, 4 to 111 ppm.

The analyses for group 4, disposition not definitely known but presumably within the Basin, represent 6 locations, 1 sample from each, except W13202, 4 samples. Two of these, W1514 and 1514A, are of low salinity: Chloride, 350 and 150 ppm; sulphate, 244 and 10 ppm respectively. The other 4 are of high salinity, taken at Locations W1353, W1364, W13202, and W15652, with the following composition ranges (partial analyses): Conductance, 1333 to 5330; boron, 29.2 to 70.9 ppm; chloride, 4127 to 19,347 ppm. The high concentrations, except boron, occur at W1353 and the lowest at W15652. The highest boron occurs at W13202, near Huntington Beach.

CHAPTER XVIII

MOVEMENT OF DISSOLVED SALTS IN THE BASIN

In respect to the South Coastal Basin as a whole, it may be considered as including (1) the high, nonarable watershed of the San Gabriel and San Bernardino Mountains; (2) a series of 3 upper basins, San Fernando, San Gabriel, and Santa Ana; (3) a series of low mountains separating the upper basins from the Coastal Plain, Santa Monica Mountains, Merced Hills, Montebello Hills, Puente Hills, and Santa Ana Mountains; and (4) the Coastal Plain, extending from the Venice Area to the Santa Ana-Irvine Area.

The more important streams flowing from the high mountain watershed into the upper basins have been measured and sampled for analysis; likewise, the streams flowing from the upper basins into the Coastal Plain. It is assumed that most of the movement of water and of dissolved salts into and out of these basins takes place as surface flow. The data available make it possible to estimate the quantities of water¹ and of dissolved salts involved in these interbasin movements during the year covered by this investigation; i. e., ending September 30, 1932. The burden of dissolved salts reported for each basin listed in Table 12 is computed from the data of discharge for each stream involved and an analysis selected as the best available representative of that discharge.

¹ The estimates of runoff here used are from the records of the Water Resources Branch of the United States Geological Survey. Mr. G. B. Gleason estimates that the figure reported in Table 12 for the Upper San Gabriel Basin represents about 90 per cent of the total mountain runoff into that basin, while that for the Upper Santa Ana represents about 70 per cent of the mountain runoff into that basin.

TABLE 12

The Estimated Quantities of Water in Acre-feet and of Dissolved Salts in Tons Moving into the Upper and Lower Basin Areas of the South Coastal Basin During the Year Ending September 30, 1932

Basin	Acre-feet of water *	Total dissolved salts, tons	Constituents in tons							
			Boron	Bicarbonate	Chloride	Sulphate	Nitrate	Calcium	Magnesium	Sodium
San Fernando Valley ¹	163,000	52,000	155	20,390	5,180	7,710	23	6,820	1,960	9,610
Los Angeles District ¹	162,000	50,000	131	18,810	6,270	7,300	92	7,050	1,800	8,240
Upper San Gabriel ²	152,000	34,000	18	18,080	272	3,050	27	8,810	2,300	1,730
Lower San Gabriel ²	81,000	30,000	23	11,970	2,580	4,490	208	5,650	1,430	3,780
Upper Santa Ana ⁴	4190,000	34,000	15	16,210	846	4,060	199	8,280	1,910	2,850
Lower Santa Ana ⁵	690,000	60,000	18	18,050	8,620	11,080	689	10,740	3,040	7,170
Total into upper basins	505,000	121,000	188	51,710	6,300	14,830	219	23,920	6,200	14,190
Total into lower basins	336,000	139,000	172	48,860	17,470	22,860	989	23,430	6,270	19,740

* The quantities here given are the measured discharges only. See tables in preceding chapters for estimate of unmeasured water.

¹ Includes water imported through the Los Angeles Aqueduct, but does not include small unmeasured inflow from mountains.

² Does not include unmeasured mountain inflow or inflow from hills.

³ Includes practically all of surface flow from upper basin but does not include inflow from hills.

⁴ Does not include unmeasured mountain inflow or inflow from isolated hills.

⁵ Includes Santiago Creek but does not include unmeasured inflow from hills.

⁶ Does not include 21,500 acre-feet net gain in Bear Valley Reservoir.

⁷ Does not include 6,550 acre-feet net gain in Santiago Reservoir.

This table shows that during 1932 there was discharged into the Coastal Plain 336,000 acre-feet of water, carrying approximately 140,000 tons of dissolved salts, including 17,000 tons of chloride. If it may be assumed that the quantity of chloride originating in the Coastal Plain is approximately equal to the quantity estimated as originating in the Upper Basin, 11,000 tons (i. e., 17,000 less 6000), then the annual chloride "crop" of the Coastal Plain may be taken at 28,000 tons. In order to maintain the existing salt balance in the Coastal Plain, that is, to discharge annually 28,000 tons of chloride, there should be discharged into the ocean enough water to carry with it this 28,000 tons.

It is estimated that under present conditions the annual discharge as sewage from the Coastal Plain into the ocean is approximately 166,000 acre-feet, or 50 per cent of the inflow of 336,000 acre-feet. Insufficient data are available to make a reliable estimate of the volume of drainage discharged annually from the agricultural lands of the Coastal Plain. This estimate of annual waste to the ocean does not include any allowance for storm waters carried by the rivers or for any seaward movement of underground waters. It should be observed that the discharges of storm waters and of deep underground waters probably are of low salinity. The data available permit only an approximate estimate of the chloride concentration of the major portion of the water now discharged as sewage from the Coastal Plain to the ocean because they do not include recent information concerning the chloride content of the sewage effluent, chiefly from the city of Los Angeles, discharged through the outfall at Hyperion. It is reported in Chapter XVII that the discharge from the plant of the Los Angeles County Sanitation District, near Wilmington, contains approximately 150 ppm chloride, while that from the Los Angeles Sewage Reclamation Plant at Griffith Park contains 85 ppm chloride.

Possibly a better understanding of salt conditions in the Coastal Plain may be had by subdividing that area at the Los Angeles River and considering each unit separately. The section west of the river is largely urban or industrial, i. e., it contains much less land devoted to agriculture than the section east of the river. According to Table 12, the western section received in 1932, 162,000 acre-feet of water containing 6270 tons of chloride. Its chief discharge of water into the ocean was 123,000 acre-feet through the Hyperion outfall, 15,000 acre-feet from the Los Angeles County Sanitation District, and 23,000 acre-feet from other coastal cities, or 161,000 acre-feet.

While data are not available as to the chloride concentration of the water discharged from the Hyperion outfall in 1932, information has been furnished by Mr. W. T. Knowlton, Sanitary Engineer for the city of Los Angeles, for that discharge in 1927. In November of that year samples were taken at two-hour intervals for one week, November 23 to 29, and titrated for chloride content. The maximum reported was 340 ppm, the minimum 106 ppm, and the mean of the seven daily composited samples was 170 ppm. The discharge during that period varied from a maximum of 195 cfs to a minimum of 65 cfs. If it may be assumed that the chloride content of the discharge of 1932 was the same as that of November, 1927, 170 ppm, and also represents the chloride of the discharge from other coastal cities, then the chloride

content of the 146,000 acre-feet would be 33,800 tons. The estimated discharge of the Los Angeles County Sanitation District for 1932 is 3000 tons of chloride in 15,000 acre-feet, making a total of 36,800 tons for the section west of Los Angeles River. This would indicate a "chloride crop" for that section of 30,500 tons.¹

For the section east of the river the inflow, also from Table 12, is given as 174,000 acre-feet, with 11,200 tons of chloride. The only discharge estimated for this section is that of the Orange County Cities Joint Disposal System, 5000 acre-feet. The chloride concentration of this discharge is given on a previous page as ranging from 517 to 1448 ppm. Accepting as the mean of these say 1000 ppm as the basis of an estimate gives 1.36 tons of chloride per acre-foot or 6700 tons annually. This leaves 4500 tons of chloride plus the annual "chloride crop" of the section to be disposed of through the systems of subsoil drainage, the volume of which is not known, or to remain in the soils of the section.

It is estimated that a safe limit of chloride concentration in the drainage water from agricultural land is 300 ppm. By way of comparison, it may be said that for the Imperial Valley for the past 3 years the mean chloride content of the drainage water has been 375 ppm, while that for the Yuma Valley has been 395 ppm. On the basis of this estimate it would require 11,000 acre-feet annually of such drainage water to carry from this section the 4500 tons of chloride mentioned above. If allowance is to be made for a "chloride crop" for this section corresponding to that of the two upper contributing basins; i.e., 10,000 tons, then it would require the discharge from the agricultural land of an additional 24,000 acre-feet of drainage water, containing 300 ppm of chloride, to maintain the salt balance of the section, or a total of 35,000 acre-feet. By way of general comment and summary it may be suggested that under existing conditions of water supply in the South Coastal Basin, allowance should be made for wasting into the Ocean as drainage from each of the agricultural areas of at least 20 per cent of the volume of inflow as irrigation water. On that basis also the discharge requirement for agricultural lands of the section of the Coastal Plain east of the Los Angeles River would be 35,000 acre-feet.

This discharge is required to clarify the subsoil waters as it is in these at present, rather than in the deep pumping strata, that saline concentration occurs. There may be present a discharge of as much as several thousand acre-feet from drains. A part of the requirement may be taken care of by additional sewage waste into the ocean as population grows.

¹ It is believed that quality of Los Angeles sewage is better at Vernon and other points along the main but no data are available.

CHAPTER XIX

INTRUSION OF OCEAN WATER

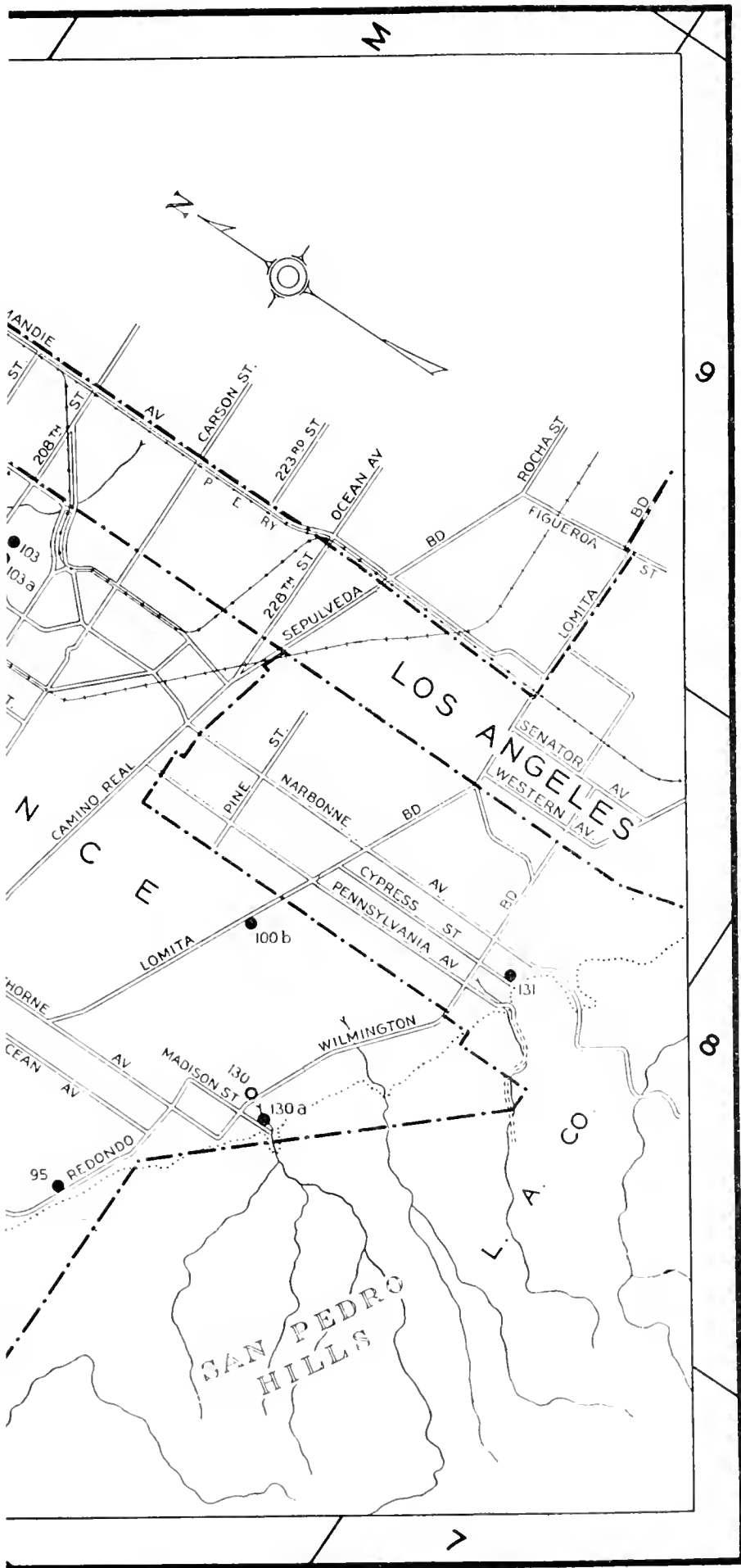
In view of the known facts that in sections of the Coastal Plain along the ocean front the static level of the underground water is seasonally or annually below sea level and that in certain sections the salinity of the underground water is very high and in some instances has increased in recent years, there has been apprehension that ocean water might be invading the underground storage basins. This subject has been under consideration in the present investigation.

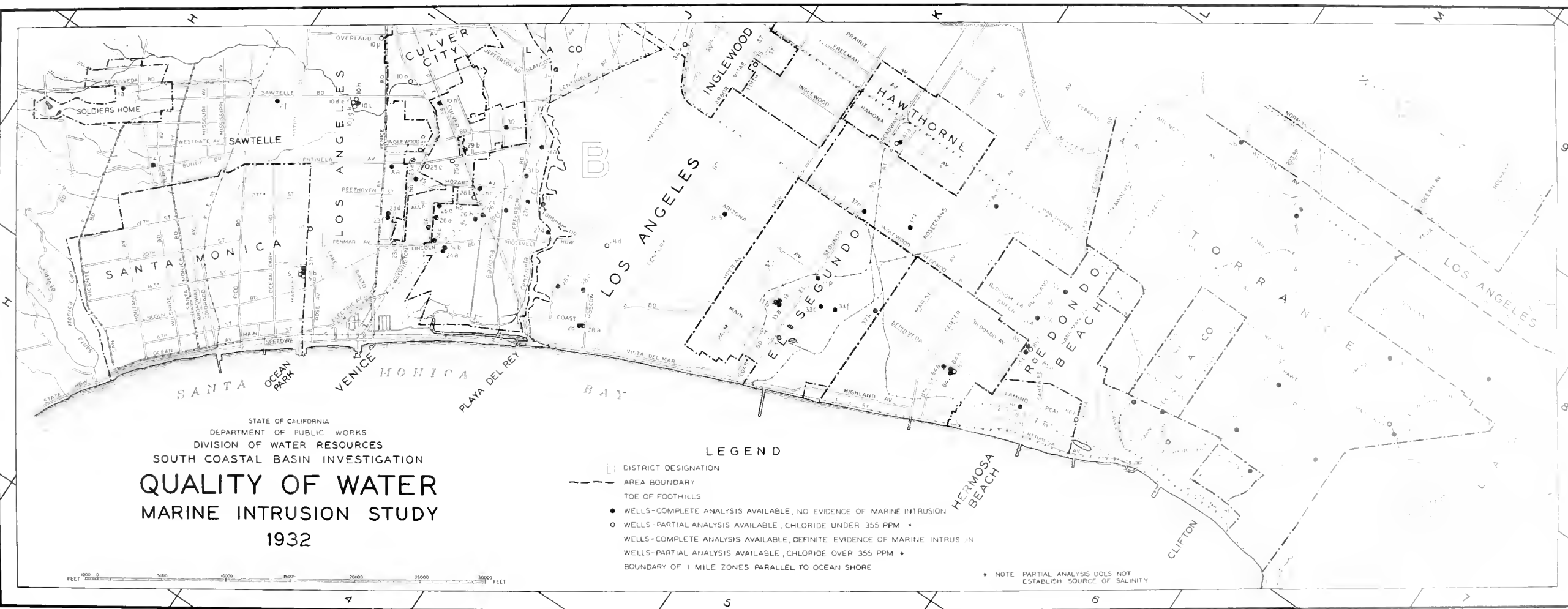
It is not regarded as essential to the present inquiry to consider in detail the evidence as to the static water levels in the various sections along the ocean front. That evidence is presented in Bulletin No. 39 of the Division of Water Resources. Consideration will be given here to the evidence available in respect to the quality of the underground water and the implications of that evidence.

It should be noted in the first place that some of the evidence heretofore available in respect to the salinity of certain wells was obtained from wells that have since been abandoned and covered or destroyed so that they were not included in the present investigation. It should be noted also that in several of the previous investigations salinity conditions were reported on the basis of the chloride constituent alone. It will be apparent from the evidence that follows that a better judgment as to the sources of salinity may be formed if some other criteria are used in addition to the chloride concentration.

The data here presented as bearing on the subject of the intrusion of ocean water have been assembled from the analytical data obtained from samples from all of the deeper wells that have been sampled, 129 in number, located along the ocean front of the South Coastal Basin from Santa Monica to Costa Mesa. The data from samples of subsoil water as obtained from very shallow wells or test holes have not been included.

As a basis for the consideration of the evidence to be presented, it is proposed to set up certain criteria by which the characteristics of ocean water may be compared with those of saline waters originating in the Basin from deep oil wells and with those of surface waters flowing into the Coastal Plain from the upper basins. These criteria are as follows: (1) Concentration as measured by total salinity expressed as parts per million; (2) concentration as measured by the chloride content expressed as parts per million; (3) ratio of calcium to magnesium expressed as the quotient obtained by dividing the milligram equivalents of magnesium into the milligram equivalents of calcium; (4) ratio of chloride to sulphate, also obtained by using the concentrations of these constituents expressed as milligram equivalents; and (5) ratio of chloride to boron obtained by using the concentrations of these constituents expressed as parts per million. The "per cent sodium," while a useful characteristic in comparing the qualities of various irrigation supplies, is not of much value in the present problem. The percentage of sodium in ocean water is 79.





The characteristics, according to these criteria, of ocean water, of saline oil-well water, and of the waters flowing into the Coastal Plain are given in Table 13. The data for ocean water are taken from those reported by Clarke in "Data of Geochemistry" as representing the means of 77 samples collected by the *Challenger* expedition, except for boron, which represents the mean of a number of analyses, made in the Rubidoux Laboratory, of samples from the Pacific Ocean along the coast of southern California, i.e., 4.65 ppm. The data for oil-well water are from the mean of 2 analyses of samples from a sump near Huntington Beach. It is not implied that all oil-well waters in the South Coastal Basin are of the same quality. Infinity is used for the ratio of chloride to sulphate in this table because these samples contained no sulphate. The data for the river water have been computed from those presented in Table 12 of this report.

In order to present the facts essential to an understanding of present conditions in the underground waters along the ocean front and, where high salinity is found, to permit inferences to be drawn as to its source, the available data are presented in Table 14, and the location of the wells are shown on Plates I and II.¹ In this table the first criterion of total salinity is expressed in terms of specific electrical conductance rather than in parts per million. Also, the wells in each zone of each Area are grouped into those of low, intermediate, and high salinity, both in respect to conductance and chloride concentrations and the number of wells in each group and in each zone is reported. In reporting the ratio characteristics for each zone the means of the ratios for each well are given and also the number of wells contributing to each mean.

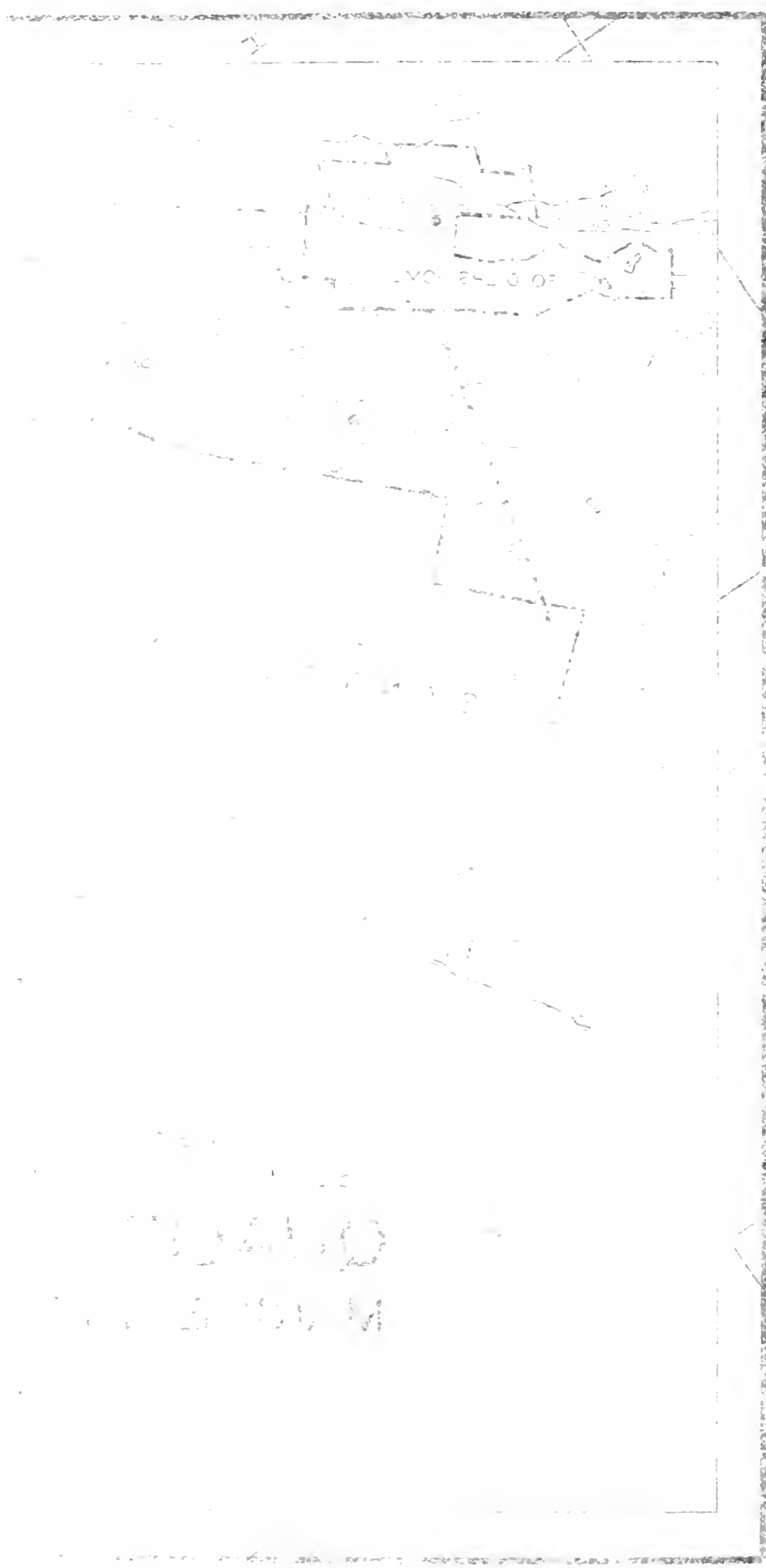
TABLE 13

The Salinity Characteristics of Ocean Water and of Oil-well and River Waters of the Coastal Plain

Item	Ocean water	Oil-well water	River water
Total salinity, ppm.....	35,000	29,620	305
Chloride, ppm.....	19,350	17,580	38
Ratio calcium to magnesium.....	.195	.586	2.27
Ratio chloride to sulphate.....	9.72	infinity	1.04
Ratio chloride to boron.....	4,090	260	101

In the Venice Area, delineated on Plate I, opposite page 86, conductances have been reported on 4 wells in zone 1, 17 in zone 2, and 13 in zone 3. The salinity is intermediate to high in zone 1, mostly intermediate in zone 2, and low to intermediate in zone 3. These results imply that there is sea-water intrusion on this front and this implication is supported by the high mean ratio of chloride to boron. The low ratio of chloride to sulphate in zone 3 is assumed to be the result of the replenishment of this zone by waters from the Santa Monica Mountains containing relatively high concentrations of calcium sulphate. It is not evident from these data that there is much intrusion of sea water into zones 2 and 3 of this Area.

¹No corresponding plate is presented for the area along that portion of Orange County adjacent to the ocean between the San Gabriel River and Costa Mesa because evidence of marine intrusion occurs in only two wells, numbered C-1274-Q-14 and C-1274b-Q-14, which are discussed in Chapters I and XV and later in this chapter.



The characteristics, according to these criteria, of ocean water, of saline oil-well water, and of the waters flowing into the Coastal Plain are given in Table 13. The data for ocean water are taken from those reported by Clarke in "Data of Geochemistry" as representing the means of 77 samples collected by the *Challenger* expedition, except for boron, which represents the mean of a number of analyses, made in the Rubidoux Laboratory, of samples from the Pacific Ocean along the coast of southern California, i.e., 4.65 ppm. The data for oil-well water are from the mean of 2 analyses of samples from a sump near Huntington Beach. It is not implied that all oil-well waters in the South Coastal Basin are of the same quality. Infinity is used for the ratio of chloride to sulphate in this table because these samples contained no sulphate. The data for the river water have been computed from those presented in Table 12 of this report.

In order to present the facts essential to an understanding of present conditions in the underground waters along the ocean front and, where high salinity is found, to permit inferences to be drawn as to its source, the available data are presented in Table 14, and the location of the wells are shown on Plates I and II.¹ In this table the first criterion of total salinity is expressed in terms of specific electrical conductance rather than in parts per million. Also, the wells in each zone of each Area are grouped into those of low, intermediate, and high salinity, both in respect to conductance and chloride concentrations and the number of wells in each group and in each zone is reported. In reporting the ratio characteristics for each zone the means of the ratios for each well are given and also the number of wells contributing to each mean.

TABLE 13
The Salinity Characteristics of Ocean Water and of Oil-well and River
Waters of the Coastal Plain

Item	Ocean water	Oil-well water	River water
Total salinity, ppm.....	35,000	29,620	305
Chloride, ppm.....	19,350	17,580	38
Ratio calcium to magnesium.....	.195	.586	2.27
Ratio chloride to sulphate.....	9.72	infinity	1.04
Ratio chloride to boron.....	4,090	260	101

In the Venice Area, delineated on Plate I, opposite page 86, conductances have been reported on 4 wells in zone 1, 17 in zone 2, and 13 in zone 3. The salinity is intermediate to high in zone 1, mostly intermediate in zone 2, and low to intermediate in zone 3. These results imply that there is sea-water intrusion on this front and this implication is supported by the high mean ratio of chloride to boron. The low ratio of chloride to sulphate in zone 3 is assumed to be the result of the replenishment of this zone by waters from the Santa Monica Mountains containing relatively high concentrations of calcium sulphate. It is not evident from these data that there is much intrusion of sea water into zones 2 and 3 of this Area.

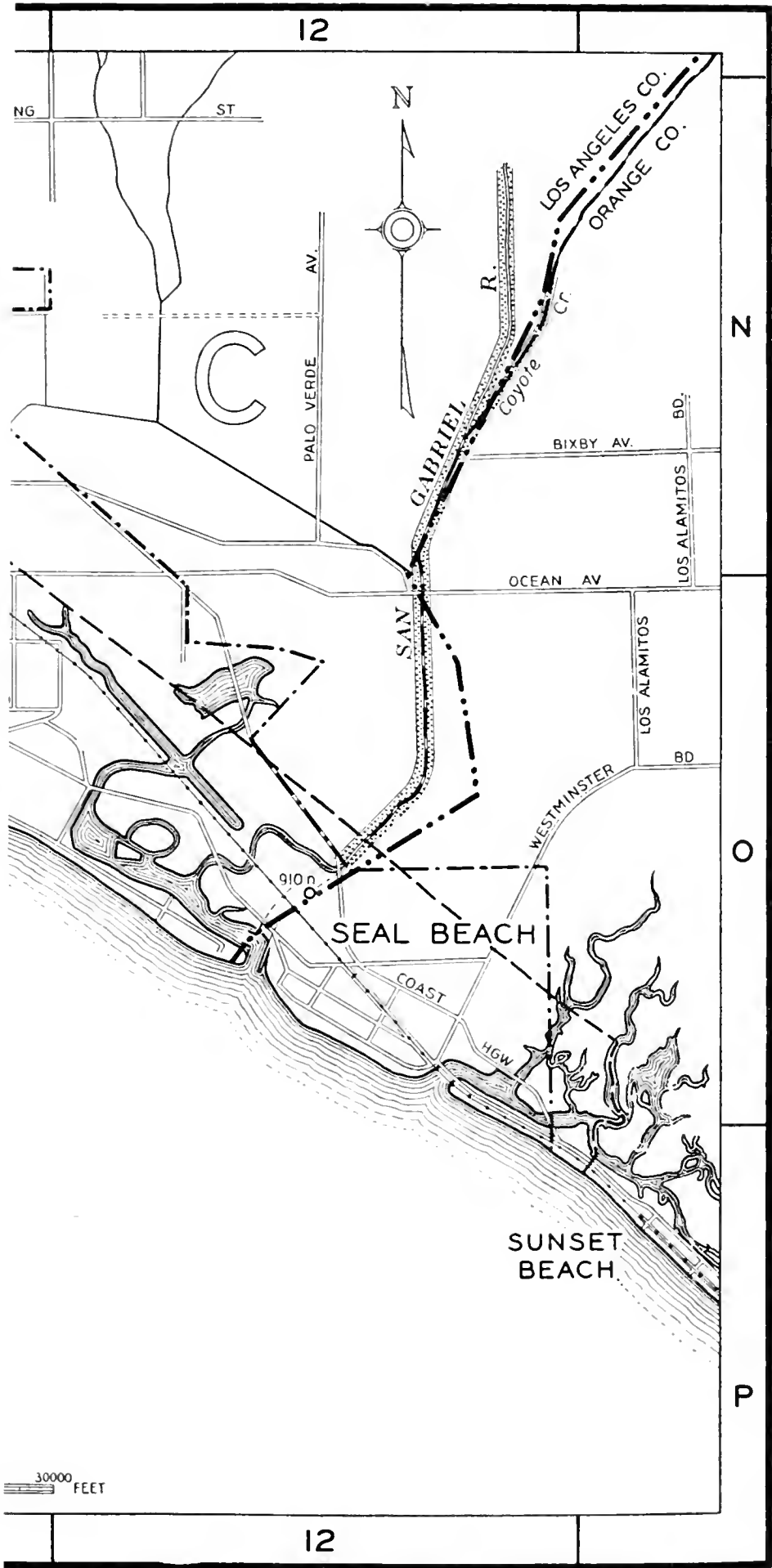
¹No corresponding plate is presented for the area along that portion of Orange County adjacent to the ocean between the San Gabriel River and Costa Mesa because evidence of marine intrusion occurs in only two wells, numbered C-1274-Q-14 and C-1274b-Q-14, which are discussed in Chapters I and XV and later in this chapter.

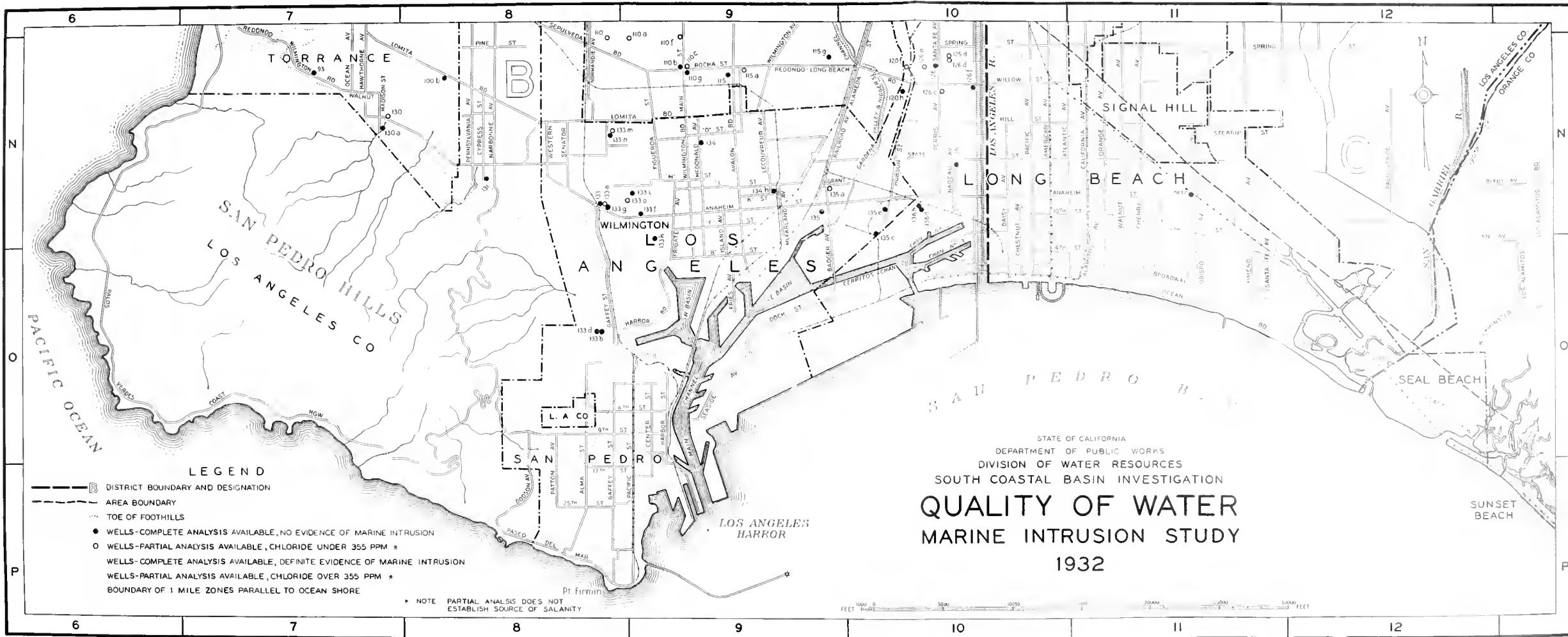
In that section of the Redondo-Long Beach Area, delineated on Plate I, opposite page 86, along the ocean from north of San Pedro Hills the evidence as to salinity shown in the table indicates that there is no perceptible intrusion even in the first zone. It has been reported that one or more wells in the vicinity of El Segundo have been abandoned because of high salinity but no data in respect to the salinity characteristics of these abandoned wells are now available. The high ratios of chloride to sulphate reported for zones 2 and 3 of this section are believed to be due to the low sulphate content of certain deep wells in this Area, referred to in the detailed discussion in an earlier chapter.

TABLE 14

The Salinity Characteristics of Wells Located within 3 Miles of the Beach from Santa Monica to Costa Mesa, Grouped as to Zones and as to Areas

Item	Zone 1		Zone 2		Zone 3	
	Number of wells	Mean ratios	Number of wells	Mean ratios	Number of wells	Mean ratios
Venice Area:						
Conductance ($K \times 10^3$ at 25°C).....	4	-----	17	-----	13	-----
Less than 100.....	0	-----	0	-----	7	-----
100 to 300.....	2	-----	15	-----	6	-----
More than 300.....	2	-----	2	-----	0	-----
Chloride content, ppm.....	7	-----	21	-----	15	-----
Less than 142.....	2	-----	6	-----	12	-----
142 to 355.....	2	-----	10	-----	3	-----
More than 355.....	3	-----	5	-----	0	-----
Calcium to magnesium.....	2	1.30	18	1.52	11	1.37
Chloride to sulphate.....	4	.69	18	1.17	11	.71
Chloride to boron.....	3	3,460	17	1,170	9	710
Redondo-Long Beach Area north of San Pedro Hills:						
Conductance ($K \times 10^3$ at 25°C).....	10	-----	7	-----	7	-----
Less than 100.....	10	-----	6	-----	5	-----
100 to 300.....	0	-----	1	-----	2	-----
More than 300.....	0	-----	0	-----	0	-----
Chloride content, ppm.....	14	-----	14	-----	8	-----
Less than 142.....	14	-----	14	-----	8	-----
142 to 355.....	0	-----	0	-----	0	-----
More than 355.....	0	-----	0	-----	0	-----
Calcium to magnesium.....	11	1.89	11	2.18	7	1.49
Chloride to sulphate.....	11	3.30	11	5.44	5	4.85
Chloride to boron.....	7	506	4	405	1	421
Redondo-Long Beach Area, San Pedro Hills to Inglewood Fault:						
Conductance ($K \times 10^3$ at 25°C).....	3	-----	10	-----	11	-----
Less than 100.....	0	-----	1	-----	7	-----
100 to 300.....	0	-----	5	-----	3	-----
More than 300.....	3	-----	4	-----	1	-----
Chloride content, ppm.....	4	-----	11	-----	15	-----
Less than 142.....	1	-----	2	-----	10	-----
142 to 355.....	0	-----	3	-----	3	-----
More than 355.....	3	-----	6	-----	2	-----
Calcium to magnesium.....	3	1.00	9	1.13	10	1.61
Chloride to sulphate.....	3	12.5	8	116.0	5	43.2
Chloride to boron.....	2	4,840	9	2,770	8	617
San Gabriel River to Costa Mesa:						
Conductance ($K \times 10^3$ at 25°C).....	13	-----	23	-----	11	-----
Less than 100.....	10	-----	15	-----	11	-----
100 to 300.....	1	-----	6	-----	0	-----
More than 300.....	2	-----	2	-----	0	-----
Chloride content, ppm.....	18	-----	42	-----	15	-----
Less than 112 ppm.....	15	-----	32	-----	15	-----
142 to 355 ppm.....	1	-----	5	-----	0	-----
More than 355 ppm.....	3	-----	5	-----	0	-----
Calcium to magnesium.....	12	2.47	21	2.32	8	2.26
Chloride to sulphate.....	12	1.17	19	6.90	8	3.35
Chloride to boron.....	10	670	17	327	8	136





In the section of the ocean front, delineated on Plate II, opposite page 88, along San Pedro Bay, between the San Pedro Hills and the Inglewood Fault line there is evidence of sea-water intrusion in 3 wells in the first zone and possibly in some of the wells in the second zone. Well 910n, in the first zone, is evidently not so contaminated. The very high ratios for chloride to sulphate in zones 2 and 3 of this section in some measure reflect the low sulphate content of waters from the deeper wells mentioned above. In the second zone, 1 well, not included in computing the ratio, is reported as having only a trace of sulphate. In the 3d zone, 5 wells, also not included in the computation, are reported as having 1 ppm or less of sulphate. Manifestly, these low-sulphate wells are not contaminated with sea water.

In the section between the San Gabriel River and the mesa southeast of the Santa Ana River, which includes Huntington Beach, the evidence of sea-water intrusion is slight. There are two wells numbered C-1274-Q-14 and C-1274b-Q-14, of high salinity in the first zone but they are located close to the beach, southwest of the fault line. While only partial analyses of samples from the standing water in these two wells are available, the high chloride concentration and their proximity to the beach indicate marine contamination. The detailed evidence indicates that the wells of intermediate and high salinity in the second zone are contaminated by oil-well waters rather than by sea-water intrusion.

In respect to salinity conditions in general in the Coastal Plain it seems safe to assume that while there is some evidence of sea-water contamination in wells located on low ground near the beach in the Venice Area and along San Pedro Bay, southwest of the Inglewood Fault, that contamination has not as yet progressed very far. Elsewhere in the Coastal Plain it seems probable that such salinity contamination as exists may be from other sources of which the water from oil wells may be an important component.



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CHAPTER XX

COLORADO RIVER WATER

In view of the fact that construction work is now under way on an aqueduct to convey water from the Colorado River to the South Coastal Basin it may be appropriate to discuss the quality of that water in this report. For the purpose of constructing and operating this aqueduct a quasi-municipal corporation has been set up known as the Metropolitan Water District of Southern California. The plan adopted involves the construction of an aqueduct, having a capacity of 1500 cfs equivalent to 1,086,000 acre-feet annually, to be completed by 1940 or shortly thereafter.

The regimen of the Colorado River in its natural state is highly variable, not only from season to season within the year but also from year to year. The concentration and composition of its dissolved salts is no less variable. In order to control and regulate the volume of the river discharge it is proposed to construct a dam in Black Canyon, a short distance below Grand Canyon, and thus create a reservoir having a capacity equivalent approximately to the normal discharge of the river for two years; i.e., 30 million acre-feet. It is expected that the existence of this reservoir above the point of diversion into the Metropolitan aqueduct will result in mixing the water so that the discharge from it will be approximately uniform in quality. Under present natural conditions the salt content of the river is relatively low during flood periods and higher during periods of low water.

The best available evidence as to the concentration and composition of the salts in the river water, expected to be found in the discharge when the reservoir is completed, is that reported by the U. S. Geological Survey from the Grand Canyon gaging station.¹ In this report is to be found, not only the detailed results of the analyses of numerous samples taken during the period named, but also, a table showing the mean concentration and composition of the salts, weighted by the volume of discharge represented by each component. This table reports conditions for each year of the 5-year period, October, 1925, to September, 1929, inclusive, and the means for the whole period.

In order to make the results of these analyses comparable with those used in this report the data that follow have been recomputed where necessary from table 2 of the report cited above. That table does not include boron as one of the constituents identified so the boron concentration reported below is the mean found in a series of samples of the river taken at the Yuma gaging station during the year 1928-29.²

Following is the mean (weighted by discharge) concentration and composition of the water of the Colorado River as sampled at the Grand Canyon gaging station for the 5-year period, except boron: Residue on evaporation (equivalent to total dissolved solids, approximate conductance 82), 571 ppm; boron, .19 ppm; per cent sodium, .37; chloride, 53 ppm; sulphate 220 ppm; nitrate, 2.4 ppm.

¹ Howard, C. S. Quality of Water of the Colorado River in 1928-1930; Water Supply Paper 638-D, U. S. Dept. Int. 1932.

² Scofield, Carl S. and Wilcox, L. V. Boron in Irrigation Waters; Tech. Bull. No. 264; U. S. Dept. Agr., 1931.

While the primary purpose of conveying water from the Colorado River to the South Coastal Basin is probably to supply domestic and industrial requirements, it is possible that some of this water may be allocated to agricultural uses; hence the consideration of the implications of such use. It may be assumed that in respect to the portion allocated to municipal uses the salt residues will largely be conveyed through sewers to the ocean. It is only in respect to the portion that may be allocated to agricultural uses within the South Coastal Basin that detailed consideration is given here.

It has been noted above that the projected capacity of the Metropolitan aqueduct is equivalent to 1,086,000 acre-feet of water annually. For the purpose of discussing the agricultural implications of the importation of Colorado River water into the South Coastal Basin these will be related to a unit volume of 100,000 acre-feet, then estimates may be made or inferences drawn with respect to such proportions of that unit volume as may be allocated to agricultural use. It may be remarked that from such information and experience as is available there appears to be no reason to believe that the water to be imported through the Metropolitan aqueduct will prove unsuited to irrigation use. The major considerations here developed relate to the effect of such importation on the salt conditions in the South Coastal Basin as a whole.

In the first place it may be pointed out that the importation of 1,086,000 acre-feet of water containing 571 ppm of dissolved solids would indicate the introduction of 843,344 tons of dissolved salts annually into the Basin in comparison with which it is shown above that the total tonnage moving into the upper basins in 1932 was 120,585 tons and that moving into the Coastal Plain was 139,465 tons. In the present connection it seems unnecessary to elaborate estimates in respect to all the salt constituents involved in this imported water or to the whole volume of it. Estimates will be made only in respect to the quantity of the chloride constituent based on a unit volume of 100,000 acre-feet, assuming that volume to be allocated to agricultural uses within the Basin.

The mean chloride content reported above is 53 ppm. This concentration in 100,000 acre-feet of water is equivalent to 7150 tons. It is estimated from the data in Table 12 that, in 1932, the volume of water passing through the Whittier Narrows and the lower Santa Ana Canyon, including the discharge of Santiago Creek, was 174,000 acre-feet, containing 11,200 tons of chloride, or 6440 tons in 10,000 acre-feet. This indicates a chloride concentration for the interbasin discharge of 47 ppm as compared with 53 ppm for the Colorado River water. In the chapter above, discussing the movement of salts in the Basin, it is estimated that there should be discharged as drainage from the agricultural lands of the Coastal Plain east of Los Angeles River, 35,000 acre-feet of water annually in order to maintain the chloride balance in that section. The contribution to that part of the Basin, either directly or indirectly, of the chloride content of 100,000 acre-feet of Colorado River water would therefore call for an additional discharge into the ocean of something like 20,000 acre-feet of drainage water containing 300 ppm of chloride, to maintain the chloride balance and insure the permanent safety of the agriculture of that section against chloride injury.

PUBLICATIONS OF THE
DIVISION OF WATER RESOURCES
DEPARTMENT OF PUBLIC WORKS
STATE OF CALIFORNIA

When the Department of Public Works was created in July, 1921, the State Water Commission was succeeded by the Division of Water Rights, and the Department of Engineering was succeeded by the Division of Engineering and Irrigation in all duties except those pertaining to State Architect. Both the Division of Water Rights and the Division of Engineering and Irrigation functioned until August, 1929, when they were consolidated to form the Division of Water Resources.

STATE WATER COMMISSION

First Report, State Water Commission, March 24 to November 1, 1912.

Second Report, State Water Commission, November 1, 1912 to April 1, 1914.

•Biennial Report, State Water Commission, March 1, 1915, to December 1, 1916.

Biennial Report, State Water Commission, December 1, 1916, to September 1, 1918.

Biennial Report, State Water Commission, September 1, 1918, to September 1, 1920.

DIVISION OF WATER RIGHTS

•Bulletin No. 1—Hydrographic Investigation of San Joaquin River, 1920–1923.

•Bulletin No. 2—Kings River Investigation, Water Master's Reports, 1918–1923.

•Bulletin No. 3—Proceedings First Sacramento-San Joaquin River Problems Conference, 1924.

•Bulletin No. 4—Proceedings Second Sacramento-San Joaquin River Problems Conference, and Water Supervisor's Report, 1924.

•Bulletin No. 5—San Gabriel Investigation—Basic Data, 1923–1926.

Bulletin No. 6—San Gabriel Investigation—Basic Data, 1926–1928.

Bulletin No. 7—San Gabriel Investigation—Analysis and Conclusions, 1929.

•Biennial Report, Division of Water Rights, 1920–1922.

•Biennial Report, Division of Water Rights, 1922–1924.

Biennial Report, Division of Water Rights, 1924–1926.

Biennial Report, Division of Water Rights, 1926–1928.

DEPARTMENT OF ENGINEERING

•Bulletin No. 1—Cooperative Irrigation Investigations in California, 1912–1914.

•Bulletin No. 2—Irrigation Districts in California, 1887–1915.

Bulletin No. 3—Investigations of Economic Duty of Water for Alfalfa in Sacramento Valley, California, 1915.

•Bulletin No. 4—Preliminary Report on Conservation and Control of Flood Waters in Coachella Valley, California, 1917.

•Bulletin No. 5—Report on the Utilization of Mojave River for Irrigation in Victor Valley, California, 1918.

•Bulletin No. 6—California Irrigation District Laws, 1919 (now obsolete).

Bulletin No. 7—Use of water from Kings River, California, 1918.

•Bulletin No. 8—Flood Problems of the Calaveras River, 1919.

Bulletin No. 9—Water Resources of Kern River and Adjacent Streams and Their Utilization, 1920.

•Biennial Report, Department of Engineering, 1907–1908.

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•Biennial Report, Department of Engineering, 1914–1916.

•Biennial Report, Department of Engineering, 1916–1918.

•Biennial Report, Department of Engineering, 1918–1920.

• Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

DIVISION OF WATER RESOURCES

Including Reports of the Former Division of Engineering and Irrigation

- *Bulletin No. 1—California Irrigation District Laws, 1921 (now obsolete).
- *Bulletin No. 2—Formation of Irrigation Districts, Issuance of Bonds, etc., 1922
- Bulletin No. 3—Water Resources of Tulare County and Their Utilization, 1922
- Bulletin No. 4—Water Resources of California, 1923.
- Bulletin No. 5—Flow in California Streams, 1923.
- Bulletin No. 6—Irrigation Requirements of California Lands, 1923.
- *Bulletin No. 7—California Irrigation District Laws, 1923 (now obsolete).
- *Bulletin No. 8—Cost of Water to Irrigators in California, 1925.
- Bulletin No. 9—Supplemental Report on Water Resources of California, 1925.
- *Bulletin No. 10—California Irrigation District Laws, 1925 (now obsolete).
- Bulletin No. 11—Ground Water Resources of Southern San Joaquin Valley, 1927.
- Bulletin No. 12—Summary Report on the Water Resources of California and a Coordinated Plan for Their Development, 1927.
- Bulletin No. 13—The Development of the Upper Sacramento River, containing U. S. R. S. Cooperative Report on Iron Canyon Project, 1927.
- Bulletin No. 14—The Control of Floods by Reservoirs, 1928.
- *Bulletin No. 18—California Irrigation District Laws, 1927 (now obsolete).
- *Bulletin No. 18—California Irrigation District Laws, 1929 Revision (now obsolete).
- Bulletin No. 18-B—California Irrigation District Laws, 1931, Revision.
- Bulletin No. 19—Santa Ana Investigation, Flood Control and Conservation (with packet of maps), 1928.
- Bulletin No. 20—Kennett Reservoir Development, an Analysis of Methods and Extent of Financing by Electric Power Revenue, 1929.
- Bulletin No. 21—Irrigation Districts in California, 1929.
- Bulletin No. 21-A—Report on Irrigation Districts in California for the Year 1929, 1930.
- Bulletin No. 21-B—Report on Irrigation Districts in California for the year 1930, 1931.
- Bulletin No. 22—Report on Salt Water Barrier (two volumes), 1929.
- Bulletin No. 23—Report of Sacramento-San Joaquin Water Supervisor, 1924–1928.
- Bulletin No. 24—A Proposed Major Development on American River, 1929.
- Bulletin No. 25—Report to Legislature of 1931 on State Water Plan, 1930.
- Bulletin No. 26—Sacramento River Basin, 1931.
- Bulletin No. 27—Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay, 1931.
- Bulletin No. 28—Economic Aspects of a Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers, 1931.
- Bulletin No. 28-A—Industrial Survey of Upper San Francisco Bay Area, 1930.
- Bulletin No. 31—Santa Ana River Basin, 1930.
- Bulletin No. 32—South Coastal Basin, a Cooperative Symposium, 1930.
- Bulletin No. 33—Rainfall Penetration and Consumptive Use of Water in Santa Ana River Valley and Coastal Plain, 1930.
- Bulletin No. 34—Permissible Annual Charges for Irrigation Water in Upper San Joaquin Valley, 1930.
- Bulletin No. 35—Permissible Economic Rate of Irrigation Development in California, 1930.
- Bulletin No. 36—Cost of Irrigation Water in California, 1930.
- Bulletin No. 37—Financial and General Data Pertaining to Irrigation, Reclamation and Other Public Districts in California, 1930.
- Bulletin No. 38—Report of Kings River Water Master for the Period 1918–1930.
- Bulletin No. 39—South Coastal Basin Investigation, Records of Ground Water Levels at Wells, 1932.
- Bulletin No. 40—South Coastal Basin Investigation, Quality of Irrigation Waters, 1933.
- Biennial Report, Division of Engineering and Irrigation, 1920–1922.
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* Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

PAMPHLETS

- Act Governing Supervision of Dams in California, with Revised Rules and Regulations, 1933.
- Water Commission Act with Amendments Thereto, 1933.
- Rules, Regulations and Information Pertaining to Appropriation of Water in California, 1933.
- Rules and Regulations Governing the Determination of Rights to Use of Water in Accordance with the Water Commission Act, 1925.
- Tables of Discharge for Parshall Measuring Flumes, 1928.
- General Plans, Specifications and Bills of Material for Six and Nine Inch Parshall Measuring Flumes, 1930.

COOPERATIVE AND MISCELLANEOUS REPORTS

- *Report of the Conservation Commission of California, 1912.
- *Irrigation Resources of California and Their Utilization (Bul. 254, Office of Exp. U. S. D. A.) 1913.
- *Report, State Water Problems Conference, November 25, 1916.
- *Report on Pit River Basin, April, 1915.
- *Report on Lower Pit River Project, July, 1915.
- *Report on Iron Canyon Project, 1914.
- *Report on Iron Canyon Project, California, May, 1920.
- *Sacramento Flood Control Project (Revised Plans), 1925.
- Report of Commission Appointed to Investigate Causes Leading to the Failure of St. Francis Dam, 1928.
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- * Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

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